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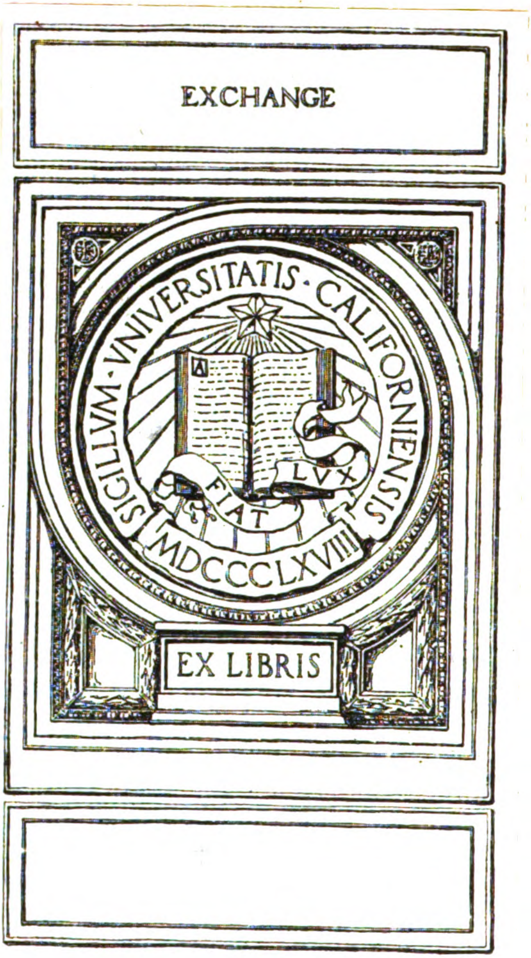
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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXCVI.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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UNIV. OF CALIFORNIA

THE INSTITUTION OF CIVIL ENGINEERS.

SESSION 1913-1914.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

16 December, 1913.

ANTHONY GEORGE LYSTER, M. Eng., President, in the Chair.

(*Paper No. 4061.*)

"Cyclical Changes of Temperature in a Gas-Engine Cylinder."

By Professor ERNEST GEORGE COKER, M.A., D.Sc., Assoc. M. Inst.C.E., and WALTER ALFRED SCOBLE, B.Sc., Assoc. M. Inst. C.E.

IN the early stages of the development of internal-combustion engines it was probably never fully realized that the mechanical, physical, and chemical problems involved were so numerous and so complex as they are now known to be; and the modern development in variety and size of these heat-engines has increased still further the need for investigation, as is shown by the ever-increasing volume of research. The range of temperature of the gas-engine charge is one problem of very great interest, and, indeed, is so bound up with the question of efficiency that it is of fundamental importance; and many investigations have been made and are still in progress on this particular matter. Much of the important work of this character has been accomplished in England, and so far back as 1882 Mr. Dugald Clerk, M. Inst. C.E., directed attention to the subject, in his calculations of the temperatures reached when mixtures of air and town gas are exploded in closed vessels.

Professor H. F. W. Burstall, M. Inst. C.E., in 1895 measured the temperature reached in the gas-engine cylinder with weak charges, and he found it desirable and even necessary to operate with twelve to fourteen explosions in 120 revolutions per minute, in order to prevent the destruction of his platinum thermometers.[1] His measurements, on an engine which did not compress the gas charge to the extent now common in practice, led him to the conclusion that the highest temperature of explosion was at least 1,250° C.[1] In some later experiments[2] temperatures as high as 1,570° were recorded, but having regard to the thickness of the wire used, these measurements are undoubtedly too low, owing to the lag of the platinum thermometer.

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[1] Philosophical Magazine, vol. xl (5th series), p. 282.

Professors H. L. Callendar and W. E. Dalby, M. Inst. C.E., in a later research,[3] used a delicate platinum thermometer, set in a jack-in-the-box valve, which shielded the thermometer at the highest temperatures; and this enabled them to measure very accurately the temperatures at various points of the compression stroke. In combination with accurate indicator-diagrams, such measurements enable the temperature for any other point to be calculated, and in this manner it has been shown that the highest temperature of explosion in a small gas-engine may be 2,250° to 2,500°.

About 4 years ago one of the Authors commenced, at the City and Guilds of London Technical College, Finsbury, an investigation of the cyclical changes of temperature in the walls and in the gas charge, and an endeavour was made to measure the highest temperatures. In this earlier work Mr. J. H. MacDowell, Demonstrator of Applied Mechanics, took a prominent part, but on his resigning his college appointment in 1910 to go to Canada the further prosecution of this research became a joint labour, which has throughout been carried on during intervals in teaching-work when the gas-engine was not required for purposes of instruction, no other engine being available. Originally it was intended to limit the investigation to a survey of the distribution and fluctuation of temperature in the walls and at the inner surfaces of the cylinder and piston of a gas-engine, but later the scope of the work was enlarged by considering the cyclical change of temperature of the gas charge.

GENERAL DESCRIPTION OF THE ENGINE AND OF THE APPARATUS USED FOR THE INVESTIGATION.

The engine is of a standard pattern constructed by the National Gas Engine Company in 1907, and has a cylinder 7 inches in diameter and 15 inches stroke. The working-volume is 577 cubic inches, and the clearance 120 cubic inches, or 17·25 per cent. of the total volume at the out position of the crank. The engine is built to develop a maximum of 12 I.HP. at 240 revolutions per minute. Thermometer-pockets entering the middle of the cylinder-wall allow the temperature to be measured along the barrel. The arrangement of the cylinder is shown in *Figs. 1* (p. 4). The end thermometer-pocket, A, enters the middle of the wall of the explosion-chamber, which is $\frac{7}{8}$ inch thick at this place, and the other three pockets enter the centre of the wall of the liner, which is $\frac{3}{4}$ inch thick. Mercury thermometers were used here, because the pockets are covered by a thickness of metal sufficient to damp out cyclical variations of temperature. The jacket-water enters at an inlet, I, near the centre of the cylinder, and escapes by an outlet, O, almost directly above the inlet. During the progress of the work an alternative outflow-pipe, AO, was fitted to the water-jacket, to ensure more effective circulation around the combustion-chamber in some experiments. One fly-wheel is provided with a separate water-cooled brake-ring, which was used in early experiments to obtain the power developed at the engine-shaft, but in later tests, when very steady running was absolutely essential, the engine drove a dynamo by means of a belt from the fly-wheel, and the current generated was wasted in a water-resistance. This latter was ultimately replaced by an air-cooled wire resistance, as it was found that the gas generated at the plates was only released at intervals, which caused sudden variations in the load. The engine was always run for about an hour before readings were taken, in order to allow the temperature to attain a steady state. The dynamo provided a very steady load, and the measured output is recorded in many of the tests. The voltmeter and ammeter used formed part of the laboratory equipment, and were of a moving-coil type not very well adapted for this kind of work. The belt losses are also somewhat uncertain, so that no important deductions are made from the results of dynamo-output.

---

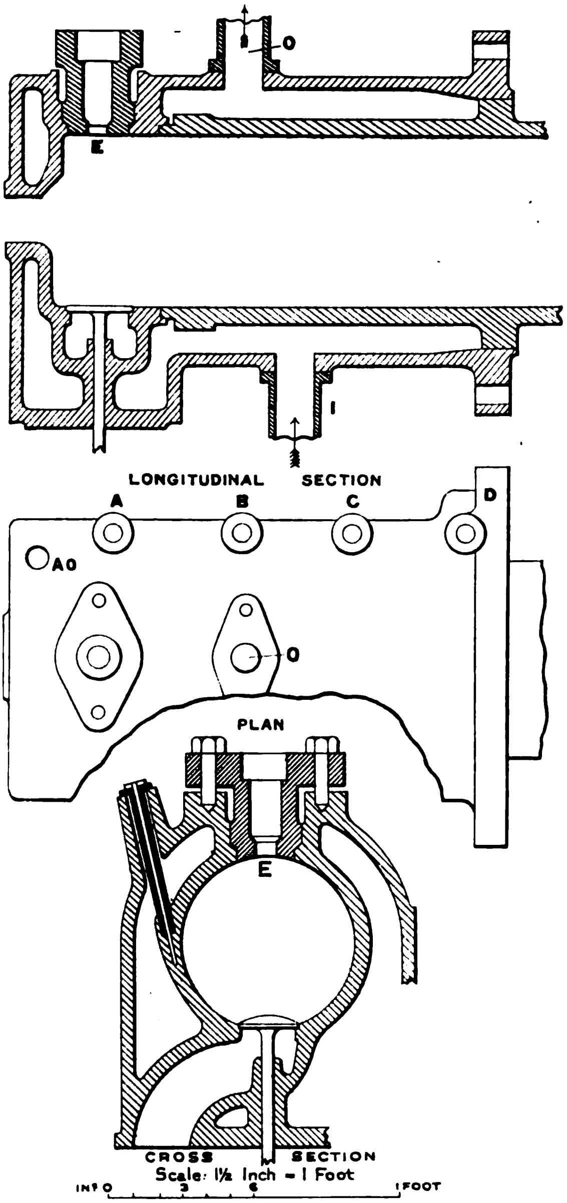
[1] The Centigrade scale of temperature is employed throughout this Paper.

[2] Second Report to the Gas-Engine Research Committee, by Professor H. F. W. Burstall. Proc. Inst. M.E., 1901, p. 1031.

[3] "On the Measurement of Temperatures in the Cylinder of a Gas Engine." Proc. Roy. Soc., Series A, vol. lxxx (1908), p. 57.

Gas-Supply.—A few of the earlier tests were made with producer-gas, but in general the supply was taken from the street-mains and measured by a separate gas-meter. In order to prevent fluctuations of gas-pressure a special form of regulator of large capacity was constructed, and was used as an auxiliary to the anti-pulsator provided with the engine. It consists (*Fig. 2*) of a vertical galvanized-iron cylinder 1 foot 8 inches in diameter and 4 feet long, provided with flexible diaphragms at both ends. The upper diaphragm is loaded directly by dead weights, A, and the lower one by a weighted lever, B. A leather non-return flap-valve, C, is also secured on the

Figs. 1.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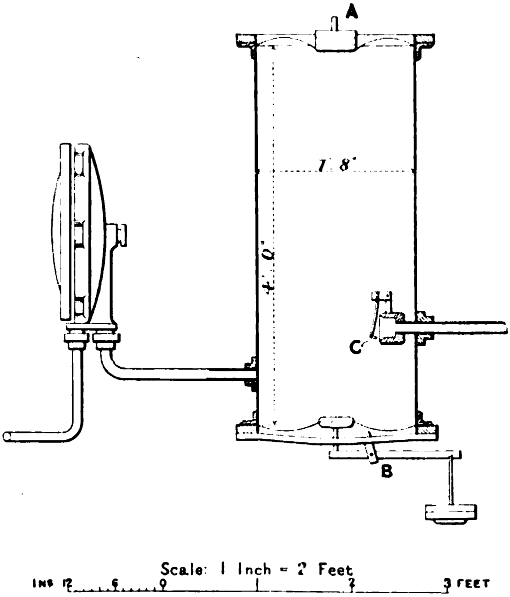
I
LONGITUDINAL SECTION
A
B
C
D
AO
O
PLAN
E
CROSS SECTION
Scale: 1½ Inch = 1 Foot
INS 0
3
6
1 FOOT

CYLINDER OF EXPERIMENTAL ENGINE.

inlet-pipe. The provision of such a large volume of gas at a predetermined pressure, and close to the engine, was found to ensure a uniform supply over long periods of time, and very steady conditions of running were obtained—an essential condition for measuring cyclical variations of temperature. A Simmance-Abady calorimeter was set up near the engine, and usually the calorific value of the gas was measured during an engine-trial. The values recorded were also compared with those obtained at the London County Council testing-station near the College. The calorific value was found to vary somewhat from day to day; for example, during the period 24 January to 13 May, 1912, the lower calorific value of the gas reached a maximum of 280 centigrade thermal units on the 7th February and a minimum of 254 centigrade thermal units on the 12th April.

Fig. 2.



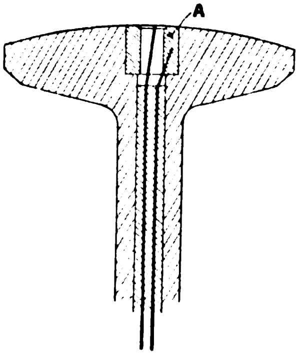
AUXILIARY GAS-PRESSURE REGULATOR.

In all the experiments, unless the contrary is expressly stated, the engine was not allowed to cut out the gas charge. The air- and gas-cocks were adjusted until there was an explosion for every two revolutions. Counters were fitted to determine the total revolutions and explosions during a trial. The jacket-water was collected and weighed. The capacity of the collecting cylinder was about 100 lbs., and the period covered by the measurement was at least 5 minutes, but was correspondingly longer for the lower rates of jacket-flow. It was therefore possible to determine the heat supplied to the engine and the quantity lost in the jacket-water. A Crosby indicator was used at first for measurements of pressure and volume, and later a Hopkinson optical indicator was especially employed for obtaining the maximum pressures reached during a cycle. The heat carried away by the exhaust gases and that lost by radiation were inferred by difference in preparing the heat balance-sheets. These data are not necessary for any of the purposes of this work, but are given as general information.

APPARATUS FOR THE MEASUREMENT OF THE TEMPERATURE OF THE WALLS AND OF THE EXPLOSIVE CHARGE.

All temperatures at or near the surfaces of the cylinder and of the valves and piston were measured by means of thermo-electric couples, except in the thermometer-pockets, as already stated. The couples are composed of cast-iron plugs, with wrought-iron wires inserted in position in a somewhat similar manner to those employed by Messrs. Callendar and Nicolson in their well-known researches on the steam-engine. A typical form of the couple used here is shown (*Fig. 3*) with reference to the inlet-valve of the engine, which is bored out axially to allow wrought-iron leads to pass to a hollow cast-iron plug inserted in the centre of the valve-face. These valves are faced so that the thickness of the metal is about $\frac{2}{100}$ inch or less; one wire is riveted through to the inner face, and the other is connected to the plug at a distance of about $\frac{1}{2}$ inch from the working face. At this distance any cyclical disturbance is completely damped out, and therefore, if the leads are connected with a suitable potentiometer, only the cyclical variation of temperature at the surface of the plug is measured. In determining mean temperatures the wire leading to the nearest point of the

Fig. 3.



THERMO-ELECTRIC COUPLE FOR THE INLET VALVE.

inner surface of the metal is used, and the other is not connected; the circuit is completed at a convenient part of the engine, which thus forms the cold junction. The wires were insulated from the metal and from each other by two-way fire-clay tubes, and in all cases the cast-iron plugs were cut from the same bar, and the wires were taken from the same hank. The calibrations of the couples were carried out in the usual manner, by determining the potential difference between hot and cold junctions when one was immersed in a solidifying metal and the other in melting ice. The calibrated values obtained did not differ very much, and, as an example, typical of several made, the Authors may cite the calibration of one of the piston couples made in July, 1910, which gave the following values:—

Hot junction, °C.	0	327	419	657
Electromotive force, millivolts . .	0·015	3·840	4·500	6·320

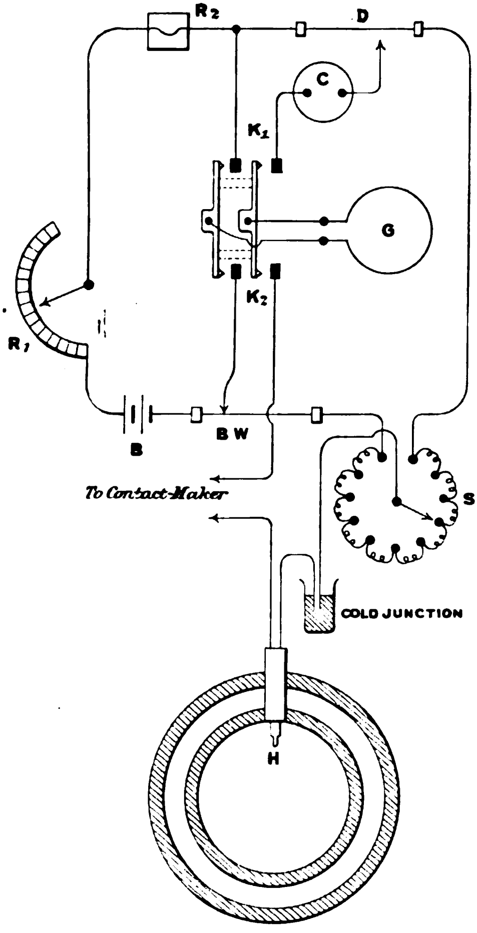
This corresponds very nearly with the formula:—

$$E \text{ (microvolts)} = -15 + 14\,T - 0{\cdot}0068\,T^2,$$

where T is the temperature in degrees centigrade.

Thermo-Electric Bridge.—The potential-differences were measured on a very convenient thermo-electric bridge, which was also used for all the determinations of temperatures in subsequent work, whether for small cyclical variations of 5°, or for the highest temperatures attained by the explosion of the charge. *Fig. 4* is a diagram of the arrangement, in which a circuit containing a battery, B, is provided with resistances, R_1 and R_2, so that the fall of potential between the extreme points of a bridge-wire, BW, can be adjusted to 1 millivolt. This is tested by the electromotive force of a cadmium cell, C, which can be opposed to the battery electromotive force by means of the upper key, K_1, an adjustable contact, D, making allowance for the known temperature-variation of the electromotive force of the standard cell used. The thermo-electric couple, H, has one lead connected to the lower key, K_2, and the other to a set of step resistances, S, in the main circuit, each of which gives a difference of potential of 1 millivolt when the adjustments are correct. In actual working, therefore, the battery electromotive force opposes that of the couple, and the readings of the bridge-wire and step resistance taken together measure the electromotive force of the couple when the galvanometer, G, shows a balance. The scale of the bridge-wire is graduated to read to 10 microvolts, and single microvolts can be estimated. For cyclical variations a rotary contact-maker is required, and when this is used the circuit is only closed for a very small fraction of a revolution, and a very sensitive galvanometer must be employed. The majority of the observations were taken when using a D'Arsonval galvanometer giving, on a scale distant 110 centimetres, a deflection of 560 millimetres for 1 microvolt.

Fig. 4.

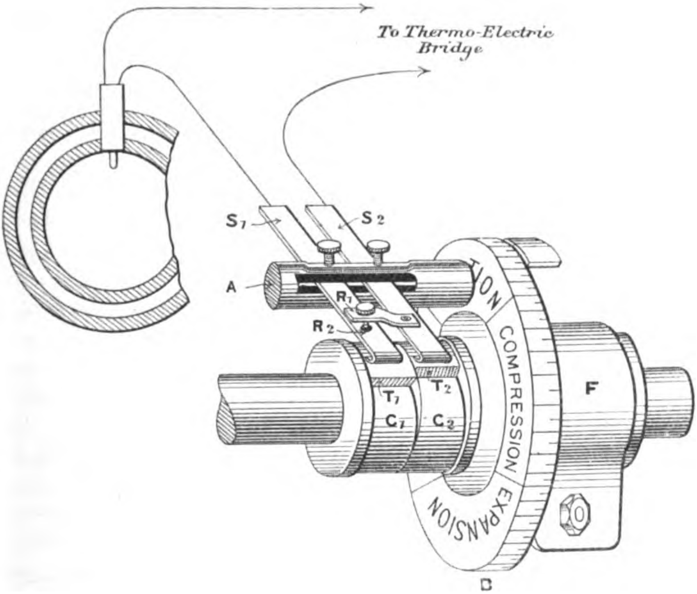


THERMO-ELECTRIC BRIDGE.

Contact-Maker.—The tapping contact employed (*Fig. 5*) is similar to one used by Professors Callendar and Dalby for their investigations of gas-engine temperatures. It consists of a pair of platinum-pointed springs, S_1 S_2, carried on the arm, A, of an adjustable wrist-plate, B, which latter is secured in a friction-grip, F, concentric with the lay shaft of the engine. A pair of cams, C_1 C_2, rotate with the lay shaft and allow the platinum point, R_1, of one spring to make contact with a platinum face, R_2, on the other spring for an interval depending on the angular distance between the two steps T_1, T_2—usually about 6° in these experiments. For a complete cycle of readings the wrist-plate is set in successive positions for the springs to make contact as the lay shaft revolves, and a balance is effected on the bridge by aid of the galvanometer. After some practice a complete cycle of twelve equidistant readings can be obtained in about 2 minutes; this corresponds with about 240 complete cycles in the engine-cylinder, so that every precaution must be taken to secure steady conditions of running during the interval, especially as the time stated is often greatly exceeded.

Factors which Limit the Power Developed.—It is desirable to discuss one phase of the behaviour of this engine before the data obtained are recorded. A considerable quantity of heat is lost to the cylinder-walls and piston of a gas-engine during the expansion and exhaust strokes. Mr. Dugald Clerk, and later Professor B. Hopkinson, pointed out that if this loss were completely suppressed, the work done by an engine developing 60 HP. would only be increased by one-eighth part. It is therefore evident that a study of the temperatures cannot lead to an appreciable improvement in the thermal efficiency of gas-engines; but, nevertheless, these temperatures are important, because they affect the design and working of an engine.

Fig. 5.



CONTACT-MAKER.

The heat lost to the metal is mainly conveyed to the jacket-water, and the heat-flow from any point is maintained by a suitable temperature-drop which increases with the distance of the point considered from the jacket. The quantity of heat given to the metal at any point will also affect the temperature, and parts which are always exposed to the gas will be hotter than those parts along the barrel which are covered by the piston at regular intervals.

Differences of temperature from point to point in the metal, such as the temperature-gradient from the centre to the edge of the piston, will produce stresses in the material; or if the temperature at any point becomes too high there will be pre-ignition of the charge. The difficulties are intensified in the case of large engines because the heat has farther to flow to the jacket, and therefore the temperatures at remote places are higher.

The power developed by an engine is mainly controlled by its dimensions, and, the speed being fixed, an overload may be taken with a rich charge. It sometimes happens that a valve-setting which gives a weak mixture one day will, on another occasion, allow a strong charge to be admitted to the cylinder. It will be seen later that the rich charges intensify the difficulties met with in an engine, by considerably increasing the temperatures.

Professor Hopkinson tested a Crossley engine of 40 B.HP., and attributed the occasional pre-ignitions with rich charges to the high temperatures reached at the exhaust-valve. His Paper leaves the impression that whereas the piston-stresses could be relieved by jacketing, the pre-ignition difficulty is more serious, because it increases in larger engines and is not so readily overcome. Pre-ignition appears to have a limiting effect on the power of an engine, and it would operate with weaker mixtures as the size of the engine is increased. The engine tested here illustrates another application of the temperature data. Careful tests failed to reveal any sign of pre-ignition at any time, although the maximum pressure was attained earlier as the strength of the mixture was increased. But with strong charges and high loads the temperature of the combustion-chamber is high, and the heat is conducted along the inlet-pipes, considerably increasing their temperature. The charge is admitted to the cylinder at a higher temperature and in a rarefied condition, and the power developed is correspondingly lower. The engine is then running under abnormal conditions; but it appears to be important to notice this phenomenon, as it is a factor which governs the power developed. It is interesting to note that this state is attained when the temperatures are not sufficient to cause pre-ignition.

Mean Temperatures of the Cylinder-Barrel.—In considering the question of the mean temperatures of the barrel it is desirable to gain some idea of the rate of flow of heat to the cooling-water of this engine. Reference to the results of trials, Table VII (p. 43), shows that on an average about 800 centigrade thermal units are supplied to the engine per minute, of which about 240 units appear as work in the cylinder, about 275 pass to the cooling-water, and the remainder is carried to the exhaust or is radiated away. In one case 416 centigrade thermal units passed through the jacket to the cooling-water per minute, but this was exceptional, as the engine was running on a very rich mixture and a high load.

The total surface available for conduction to the water-jacket, including the piston-area, is about 3½ square feet, and the surface area of the compression-space is rather more than 1 square foot; so that, even under the most favourable circumstances, the flow of heat cannot be greater than about 400 centigrade thermal units per square foot per minute. Calculation shows that for this flow the mean difference between the temperatures of the inner and outer surfaces of the cylinder-barrel is less than 40°, and therefore, unless the cyclic variation of temperature at the inner surface is very considerable, the mean temperatures at the centres of the cylinder-walls must be very moderate.

It will be shown later that the temperature of explosion in this engine lies between 1,800° and 2,250°, according to the conditions of running. How far this will affect the temperature at the middle of the walls may be estimated by assuming, as a simple hypothesis, a sine-wave temperature-variation of amplitude $T = 100°$ per cycle at the surface. It can be shown[1] that the fluctuation of the temperature, T, at a depth x in the metal is expressed under these circumstances by $T_1 = T \operatorname{Exp}\left(-\sqrt{\frac{\pi N}{2d}}\, x\right)$, where N represents the number of revolutions of the engine per minute, and d is a constant depending on the diffusivity of the metal. The temperature will also be in step with that at the surface at a depth $2\pi\sqrt{\frac{2d}{\pi N}}$, and the range of variations there will then be $T/\operatorname{Exp}(2\pi)$, or, say, $T/529$. Taking $N = 200$, which corresponds with average conditions of running, and $d = 1 \cdot 2$, it is found that at a depth of ⅜ inch the fluctuation is less than ⅛° under the assumed conditions. Experiment shows that the surface variation is always very much less than 100°, and it may therefore be expected that the barrel-temperature will be found to be quite low; and, as the cyclical variation is not appreciable at the centre of thickness, it is justifiable to use mercurial thermometers for these observations.

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[1] Prof. E. G. Coker, "The Temperatures of the Walls of a Gas-engine Cylinder." *Engineering*, vol. lxxxvi (1908), p. 497.

The temperatures along the barrel have received attention in a previous Paper already cited, but the results are repeated here in Table I, and are illustrated in *Fig. 6*. The plug-temperatures given were measured by means of an iron-manganin surface couple inserted at E, *Fig. 1*. Mean readings were taken with a millivoltmeter, which was also used in the calibration. These tests were made before the jacket-outlet was modified, and therefore the water left at the centre in all cases. In all the other tests the jacket-outlet was at the back, unless the contrary is expressly stated. One series of these tests was made with producer gas, but in all other cases town gas was used.

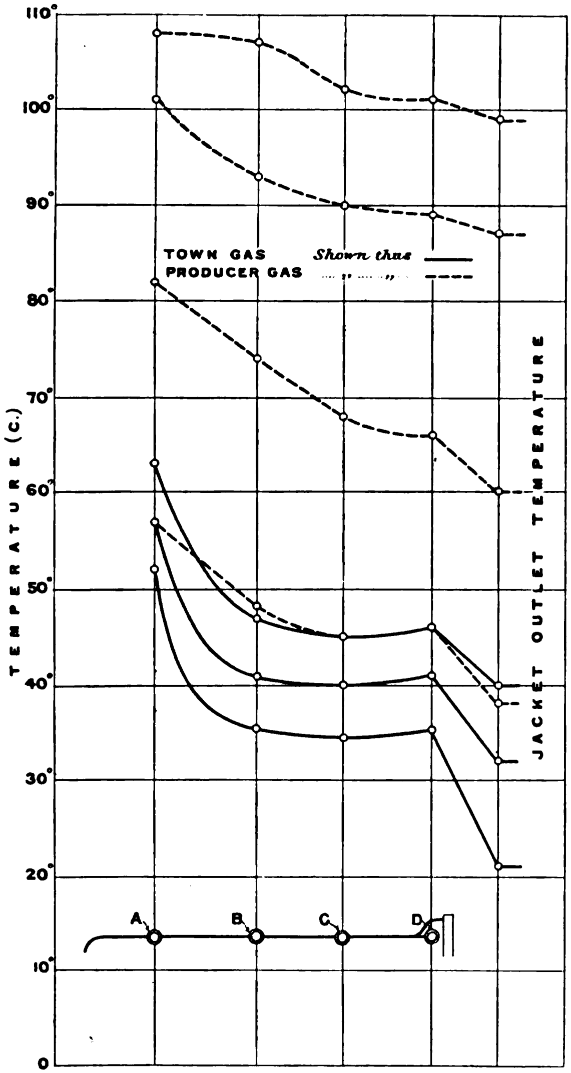
The data from the later tests are given in Table II and plotted in *Fig. 7*. The maximum pressure attained in the cylinder is included, to indicate the strength of the mixture. The indicated horse-power is not given in all cases, because, for the limited range dealt with, the power has little effect on the barrel-temperatures. The quantity of jacket-water flowing, and consequently its outlet temperature, has by far the greatest effect in controlling the temperature of the mass of the metal. The temperature of the barrel rises with that of the jacket-outlet, and sometimes (as, for example, in Test No. 8) the latter is above the former, except at the combustion-chamber. This appears to emphasize the necessity for a jacket water-outlet at the back of the cylinder. The richer mixtures of town gas cause a high temperature at the combustion-chamber, which is not maintained along the barrel, whereas the temperature-drop is very gradual in the producer-gas tests. Comparing tests Nos. 15 and 16 it will be seen that the direction of flow makes very little difference when the flow is great and the temperatures are consequently low.

The rich charges fire early, and a very high gas-temperature is attained, whereas with the weaker mixtures the maximum temperature of the gas is considerably lower, and is not reached until somewhat late in the stroke.

When the jacket-water leaves at the centre the temperature of the metal is nearly always above that of the water at the outlet; but when it leaves at the back it is further heated over the combustion-chamber. If the outlet temperature of the water is high, it is above that of the metal except at the inner end of the cylinder.

The experiments show that only a small temperature-drop is

Fig. 6.

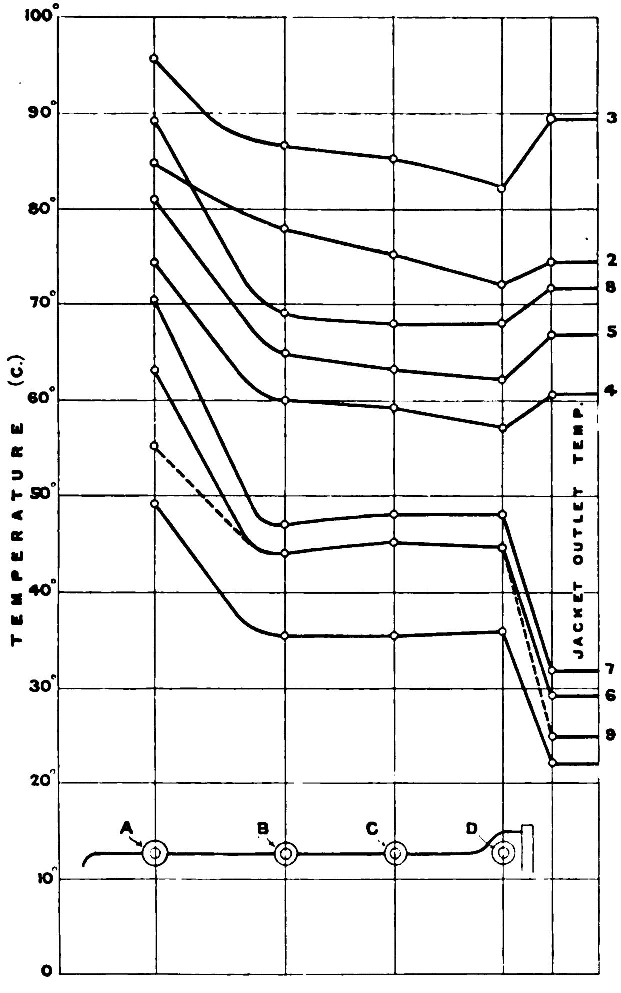


TEMPERATURES OF THE CYLINDER-BARREL.

required from the metal wall to the jacket-water. The metal of the cylinder is never very hot, except in the region of the combustion-chamber.

The Surface Temperatures.—The first attempts to measure the

Fig. 7.



Temperatures of the Cylinder-Barrel.

fluctuations of temperature at the surface of the cylinder were made in May, 1908, at the aperture E, immediately above the exhaust-valve. A cast-iron plug, bored out to have a central thickness of 0·015 inch, was forced into the casting closing the cylinder at this place. A wire of soft iron was soldered to the outer face at the centre, and a second wire completed the circuit, which included the contact-maker and bridge.

This arrangement could be used to obtain the fluctuation of temperature at a point 0·015 inch in the metal, and also the mean temperature at the same point.

At first considerable difficulty was experienced in measuring the small cyclical change, but finally this was overcome by using a very sensitive low-resistance galvanometer for indicating zero readings on the bridge-wire.

As an example of the order of magnitude of the cyclical change at the aperture E, the following set of readings for a trial on the 5th June, 1908, may be given. These measurements were made with the engine running at 220 revolutions per minute, and developing 9·6 B.HP. The mean temperature at the plug was about 240°.

Crank-angle .	0°	60°	120°	180°	240°	300°	360°	420°	480°	540°	600°	660°	720°
Microvolts. .	154	150	145	135	125	116	148	193	188	174	160	154	156

These values are plotted in *Fig. 8*, and, as might be expected, they show some lag, owing to the measurements being averages over a crank-angle of 15°, and also to the thickness of the metal.

The extreme range of temperature corresponds with 77 microvolts, and the calibration shows that

$$E = -15 + 14\,T - 0{\cdot}0068\,T^2 \text{ approximately.}$$

Hence

$$\begin{aligned} \frac{dE}{dT} &= 14 - 0{\cdot}0136T \\ &= 14 - 0{\cdot}0136 \times 240 \\ &= 10{\cdot}64 \text{ microvolts per } 1^\circ. \end{aligned}$$

This corresponds with a fluctuation of $T = 7{\cdot}2^\circ$ at this point. The fluctuation T at the surface will be greater, and is obtained from the formula

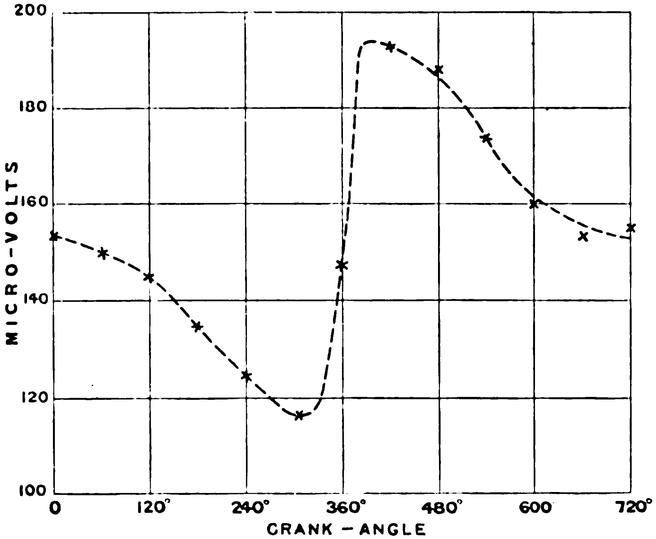
$$T = T \operatorname{Exp}(-mx),$$

where $m = \sqrt{\frac{\pi N}{2d}} = 16{\cdot}97$ at 220 revolutions per minute

and $x = 0{\cdot}015$ inch.

This gives a surface fluctuation of 9·3° due to cyclic change of temperature of the gas-engine charge[1]—a surprisingly small amount, since the charge itself varies 1,800° or more. It is apparent at once that no cyclical change worth considering can be developed in the liner, as it is not subjected to the full effect of the explosion, while the movement of the piston tends to smooth out temperature-variations. Attention is therefore directed to special places in the combustion-chamber where measurements are likely to be appreciable, and for which it is important to obtain the mean temperatures. The points selected are the centre of the inlet and exhaust valves and points on the vertical diameter of the piston.

Fig. 8.



Surface Temperature Changes.

The general arrangement of the couples in both inlet and exhaust valves is shown in *Fig. 3*, and the arrangement permits of measurements being made at the surface. The construction of the valve-couples for the later tests is also indicated in *Fig. 3*. The valve-stems were bored out to a convenient diameter, and faced plugs, A, of cast iron were inserted, each having two connecting leads of wrought-iron wire, one of which came to the inner surface whilst the other was embedded in the metal. Five cast-iron plugs were inserted in the vertical diametral plane of the piston, as shown in cross section, *Figs. 9*, and one wire only was led from each piston couple, a long coiled spring supplying the flexible connection required by the motion of the piston. All the iron wires were riveted into the cast-iron plugs. No. 2 piston couple was blown out during a trial and had to be plugged, and No. 4 was not used during these tests. The same materials were used in making all these couples, and the calibrated relation of electromotive force to temperature was in all cases practically the same as that already given.

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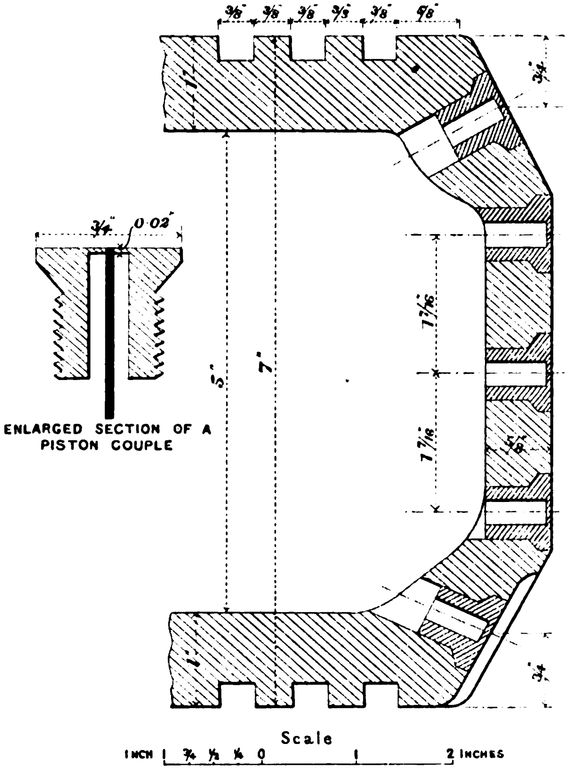
[1] See also Minutes of Proceedings Inst. C.E., vol. clxxvi, p. 57.

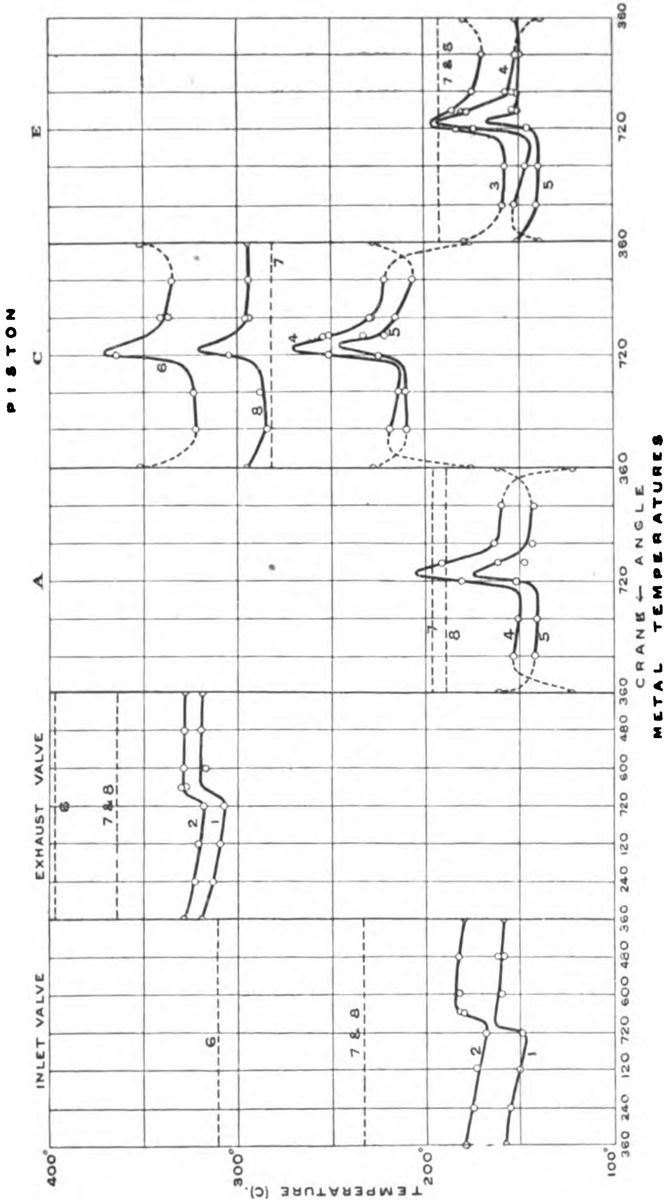
Figs. 9.



Cross Section of Piston showing Positions of Couples.

The data from these experiments are given in Table III and *Fig. 10*. Measurements were made at five points, namely, at the centre of the inlet and the exhaust valves, and at the top, centre, and bottom of the piston. The highest temperature was recorded at the exhaust-valve, and the maximum there was practically

Fig. 10.



400°. When the conditions were changed so that the temperatures increased, the addition at this place was less than at other points of lower temperature, except, perhaps, at the outside of the piston, where it was better controlled by the water-jacket. The maximum temperature at the inlet valve was 300°, and at the centre of the piston its maximum mean value was about 340°. These figures indicate large increases over the temperatures which obtain with weaker mixtures, and illustrate the cause of the rarefaction of the charge and the resulting loss of power in extreme cases. The range in temperature at the inlet valve is from 12° to 18°, and at the exhaust-valve it is about 12°. The range is greater at the surface of the piston, particularly at the top and centre. In test M4 the range at the centre of the piston is certainly not more than 80°, and at the top, in the same test, it is not more than 68°. This test, M4, was with a medium mixture and a cold jacket. All the couples show a low temperature at 360° crank-angle, which corresponds with the commencement of the suction stroke. An increase in either the jacket-temperature or the strength of the mixture was sufficient to eliminate the low temperature at this point, and consequently to reduce the range. In many cases this point becomes one of high temperature—a fact which might be explained by the high temperature of the inlet valve and of the cylinder end. There is very little difference between the temperatures at the bottom and top of the piston.

Professor Hopkinson obtained a mean temperature of 400° at the exhaust-valve under medium conditions. He considered that with heavy charges the temperature at this point might reach nearly 500°, and there would be danger of pre-ignition. This temperature is higher than that recorded in the Authors' tests, and the small rise with a richer mixture indicates that for this smaller engine it would never greatly exceed 400°. There is no difficulty due to pre-ignition in this engine, as on account of its small size this trouble is avoided. Nevertheless, the jacket-loss alone in the test, M6, which gave the high temperature, was 44 per cent., whereas Professor Hopkinson gives 34 per cent. as the maximum value for his combined jacket- and radiation-loss. He obtained a mean temperature of 250°, at the centre of the inlet valve, as compared with 311° here, accompanied by a cyclical variation of 15°.

The temperature-gradient from any point to the jacket is that required to maintain the flow of heat. Therefore Professor Hopkinson divided the temperature-drop by the total heat-loss due to radiation and to the jacket. The heat-flow from any region is approximately proportional to the temperature-gradient, and since he found that the quotient was approximately constant under all conditions, it followed that the same proportion of the lost heat was taken by the parts considered at all times. This applied to the piston, but there was slight evidence that it took a larger share with weak charges.

The present results are treated in a similar manner for the centre of the piston. The mean jacket-temperature is taken, and therefore in the following Table it always appears to be low.

Test.	I.HP.	Maximum Pressure.	Piston Temp.	Mean Jacket Temp.	Difference O.	Heat Jacket H.	O/H.
		Lbs. per Sq. Inch.	°C.	°C.	Temp. °C.		
M 6	10·36	418	339	34	305	416	0·732
M 7	10·26	347	282	27	255	322	0·791
M 8	9·74	356	294	29	265	316	0·84
M 4	10·94	375	224	27	197	286	0·69
M 5	10·7	365	215	47	168	246	0·683

The last pair of tests, made on the same day on a high load and a medium mixture, indicate that the temperature of the jacket does not appreciably affect the proportion of the heat taken by the piston, since the ratio of the temperature-gradient to the jacket-loss is nearly constant. The constant was little different for the very rich mixture used in test M6, but is much higher in the other two tests. The constant appears to depend mainly on the load, and increases as the load is diminished, indicating that the piston takes a larger share of the lost heat at lower loads.

It was also noticed that the constant increased uniformly when the tests were arranged in the order of the date in which they were made. It was thought possible that the surface of the piston was becoming dirty. Two tests were made on the 30th May, 1912, to check this point. The engine was run to develop approximately 10 I.HP. on a weak mixture, first with the jacket running cold and then with a hot jacket. There was no other change in the adjustments. The temperatures recorded at the centre of the piston were 206° and 190° respectively, and the calculated ratios were 0·724 and 0·69. These results confirmed the view that the piston could not have become appreciably coated by the small amount of running between the dates of the metal-temperature tests.

The Temperature of Explosion of the Gas Charge.—The difficulty of determining the maximum temperature of explosion in a gas-engine is generally appreciated, as it is above the melting-point of such an infusible metal as platinum, and a wire of this metal thin enough to follow the cyclical change of temperature invariably fuses under ordinary conditions of running, while a stout wire $\frac{1}{1000}$ inch or more in diameter does not reach the temperature of explosion, and its indications show considerable lag. Early experiments, however, showed that alloys of platinum with rhodium and iridium respectively were able to withstand the temperature of explosion near the walls for some hours, or even days, when made into thermo-couples $\frac{5}{10,000}$ to $\frac{8}{10,000}$ inch thick, provided the engine were not overloaded. The electromotive force of couples of this kind is 7 to 8 millivolts at the highest temperature, and although this is very small, it can be measured with great accuracy on the bridge described above. A sufficient stock of these alloys, in the form of fine wires, was obtained from Messrs. Johnson, Matthey and Co., and calibrated. The calibrations were kindly checked for the Authors by Dr. Harker at the National Physical Laboratory, up to 1,283°, as shown in the following Table :—

Temperature °C.	0	490	840	1,003	1,283
Electromotive force, millivolts	0	3·152	5·036	5·773	6·382

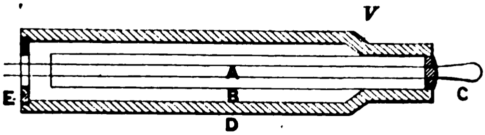
The results corresponded well with the formula :—

$$E \text{ (microvolts)} = -174 + 7\cdot6075\,T - 0\cdot001673\,T^2,$$

and this was used to determine the temperatures corresponding with the values obtained in the trials, on the assumption that it held for extrapolated values beyond the range of calibration. The electromotive force of the couple, at the melting-point of platinum, was measured later and found to be 7·8 millivolts, when the cold-junction temperature was 22°.

There is some uncertainty as the melting-point of platinum, but a generally accepted value is 1,755° ± 20°. Taking 1,755° as correct, the formula gives 7·975 millivolts instead of 7·8 millivolts. This experimental value was obtained by observing the electromotive force produced in a couple when the junction was immersed in a solidifying platinum bead, previously melted in an adjustable oxy-hydrogen flame. This check measurement indicates that the extrapolation values are fairly correct. In the final measurements of temperature it has not been necessary to use extrapolated values of temperature. Considerable experience was obtained in making and using couples of this kind before the final arrangement shown in *Fig. 11* was adopted. The couple was encased in a steel sheath formed as a conical valve at V, and this was pressed against a seating in the casting at E, *Fig. 1*, and closed the opening immediately above the combustion-chamber. The sheath was kept in place by a hollow screw bearing on it. A two-way fire-clay tube, A, containing the couple, was secured in this sheath with plaster of Paris. The inner ends of the wires were rolled out to the required thickness and fused together electrically, and afterwards the junction was finally rolled to a thickness of $\frac{5}{10.000}$ to $\frac{8}{10.000}$ inch; the strip so formed was trimmed down to approximately the contour of two truncated triangles with the central junction at the narrowest part. This form was adopted to provide a loop strong enough to hang in a vertical position in spite of the violence of the explosion, and it was therefore set with the planes of its flat faces parallel to the axis of the cylinder, to offer the smallest obstruction. Experience showed that this loop served remarkably well, and if not fused by an abnormal explosion it retained its shape, although the edges, when examined through a magnifying glass, sometimes showed signs of fusion and consequent thickening after long exposure. In order to test the delicacy of the indications of these couples at low temperatures, Mr. McDowell made a number of experiments when the engine was motored round with the exhaust-valve locked. Having regard to the fact that the air in the cylinder was never entirely freed from moisture, very fair agreement was obtained between the temperatures calculated from the compression and expansion and those obtained from the thermo-couples. In a good many explosion experiments the couple gave way suddenly after experiencing many thousand explosions without showing any signs of failure. In some cases the couple was fused, and in others mechanical breakage occurred. The electromotive force obtained at the highest temperatures of explosion varied between 7 and 8 millivolts, and two of

Fig. 11.

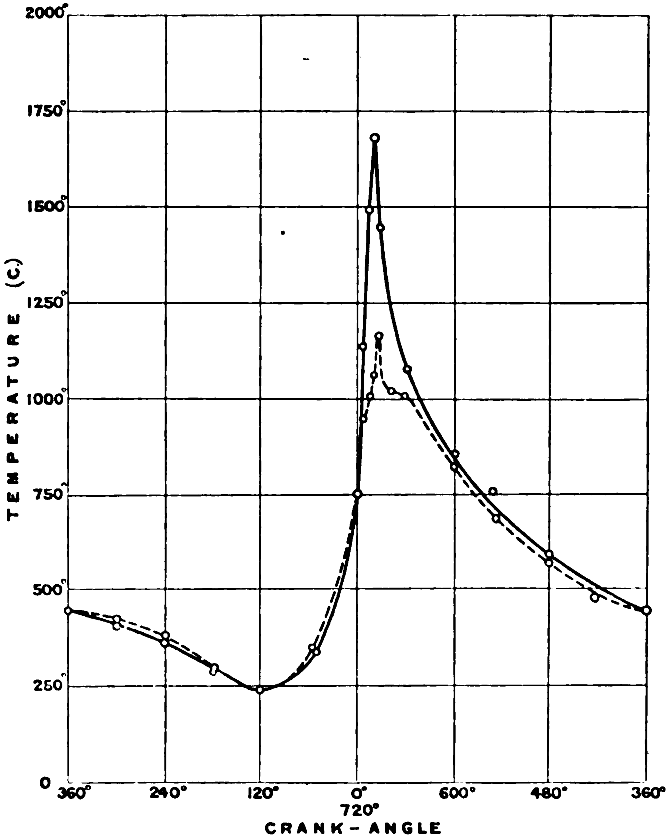


Final Arrangement of Thermo-Electric Couple for Measuring the Temperature of Explosion.

the early determinations of the temperature-cycle of the gas charge are shown in *Fig. 12* and Table IV.

The maximum temperature recorded here is 1,675°. Taking into account the cold-junction temperature, this gives a maximum temperature of 1,705°. In this case a further estimate of the highest temperature was obtained, for, although the engine appeared to run perfectly normally throughout, the electromotive force of the couple suddenly became lower at the explosion-point, although at other points it remained much the same. On taking out the couple it was found that this was due to the junction fusing without

Fig. 12.



TEMPERATURE-CYCLE OF GAS IN CYLINDER.

breaking, so that the temperature must have reached the fusing point of one of the alloys. The fusion temperature of platinum is approximately 1,750°; for rhodium it is probably in the neighbourhood of 1,920°; and for iridium about 2,300°. Until lately, there appears to have been no certain knowledge of the melting-points of the alloys of these two latter metals with platinum, although it was known that the 10-per-cent. alloys used both melt at temperatures above 1,750°. Some recent experiments made by Dr. Harker at the National Physical Laboratory on these 10-per-cent. alloys show that they melt at very nearly the same temperature, and at about 100° higher than the melting-point of platinum. This affords an independent estimate of the temperature attained at the melting of the wire, of about 1,850°. In a former Paper,[1] using the data available at the time, this temperature was estimated to be between 1,850° and 1,950°. The cyclic variation of this couple before and after fusion is shown in *Fig. 12*, and it will be noted that the lower temperatures are considerably above the temperature of the incoming charge. This cannot be due to the want of sensitiveness of the couple at low temperatures, as the motoring experiments with air showed that the couples were capable of following the temperature with considerable accuracy. It must therefore be due to some other cause, and it seems probable that the flow of heat from the walls, and still more the effects of radiation, maintain the gas around the couple at a higher temperature than the incoming charge. The temperature of the gas in the cylinder is not that of the incoming charge, since this is mixed with the high-temperature products from the clearance-space. The later experiments indicate that the measured temperatures are truly those of the gas. The measurements showed that in these ($\frac{3}{4}$-load) trials a temperature of about 1,800° was reached at a distance of about $\frac{1}{2}$ inch from the walls. In order to ascertain whether this temperature is exceeded at the centre of the cylinder, a comparative experiment was made by inserting a stout couple at distances of $\frac{3}{8}$ inch from the walls and at the centre, $3\frac{1}{2}$ inches away. In order to support this couple at the centre, the fire-clay tube was continued to within $\frac{1}{2}$ inch of the centre, and readings were obtained as shown in the Table on p. 25, in which the electromotive force at the centre-line was found to be always greater than that near the walls. The lag of the couple was so great, however, that no quantitative estimate could be made of the temperature at the centre, but the readings indicated that the highest temperatures were reached at the centre of the cylinder.

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[1] "The Cyclical Changes of Temperature in a Gas-engine Cylinder near the Walls." Report of the British Association, 1910, p. 710.

Crank-angle	380°	390°	400°	410°	420°
Couple ⅜ inch from walls, millivolts	5·32	5·64	6·20	6·24	6·30
Couple at centre-line of cylinder, millivolts	5·52	6·18	6·33	6·49	6·42

In order to remove some uncertainty as regards the influence of the lag of the couple at the very rapid changes of temperature during explosion, some further experiments were made with the addition of an optical indicator to measure the highest pressures obtained during the explosion. The pressure, volume, and temperature were measured at near points on the expansion-curve, to obtain the value of the constant from which to calculate the temperature corresponding with the maximum pressure.

Three types of indicator-diagrams were taken, a normal diagram with a 200-lb. spring, another in which the drive was taken from the half-speed shaft, and the phase altered to draw out the explosion part, and a third with a 40-lb. spring. In this way the pressure was determined with considerable accuracy for any angle of the crank-shaft, and the exact position of the maximum pressure was determined. The values of PV/T for a number of points on the compression- and expansion-curves were obtained, and a typical set of results is tabulated on p. 26.

A value of PV/T was selected from the calculated results for the expansion stroke, the compression results being used as a check. In the case of the Table on p. 26, the selected value was 21·45, and it was not necessary to correct for the molecular contraction during combustion as all the measurements are on the expansion-curve. The highest temperatures were calculated from this constant, the measured pressure, and the known volume; as illustrated in the case of the maximum temperature for this test, which corresponds with the maximum pressure attained at 15° past the dead centre. It may be mentioned here that the gear driving the lay shaft of the engine was tested for back-lash: this was found to be of negligible amount, and it causes no appreciable error in the angular readings of the tapping contact.

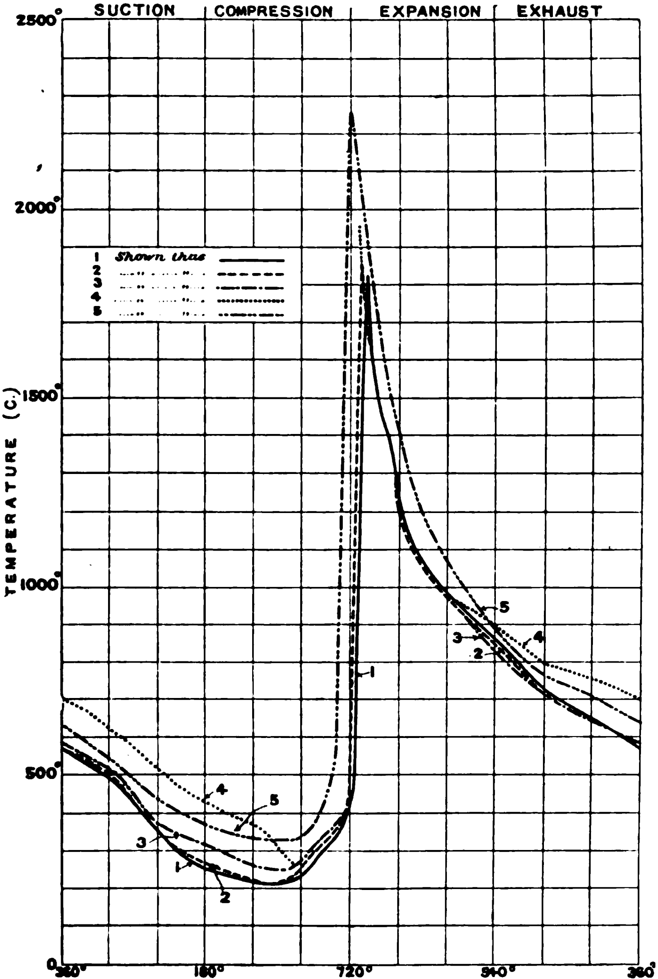
The modified indicator-diagram gives very accurately the angular position of the crank corresponding with the maximum pressure, and allows the maximum temperature to be estimated with con-

Angle.	Absolute Pressure.	Volume.	Recorded. Temperature Absolute.	PV/T.	True Temperature Absolute.	True Temperature.
°	Lbs. per Sq. Inch.	Cu. Ins.	°		°	° C.
			Compression.			
15	108·0	130·4	641	22·0		
30	81·3	165·0	603	22·2		
45	57·1	220·0	570	22·0		
60	41·3	283·0	546	21·4		
			Expansion.			
645	84·5	358·0	1,376	22·0	1,410	1,137
630	63·1	439·0	1,328	20·9	1,392	1,019
615	53·7	516·0	1,295	21·4	1,391	1,018
600	45·9	576·0	1,261	21·0	1,234	961
705	353·0	130·4	..	..	2,144	1,871

siderable accuracy, because the volume is calculated from the crank-angle. If the constant is wrongly determined, the temperatures are in error to about the same degree; but inaccuracy is more likely to arise from the measurement of the maximum pressure than from an error in the constant, since there is a greater percentage variation in the maximum pressure and temperature from stroke to stroke, even with the steadiest running, than is caused by an error in the selection of the constant. The maximum pressure was measured on the modified phase-diagram and checked by the ordinary diagram, and the results agreed very closely. In this test the maximum temperature is found to be 1,870° for a value of the constant of 21·45. If this constant had been taken as 20·9 the calculated temperature would be 1,930°, and if as 22, 1,830°. The extreme values of the constant therefore affect the calculated maximum temperatures to the extent of 100°. Comparison with the compression values shows that 22 is too high a value if the contraction of the volume at explosion is allowed for, and the most probable value is therefore not very different from that taken.

A number of determinations of maximum temperature are recorded in Table V and *Fig. 13.* The engine in all cases was adjusted to fire at every two revolutions, because a miss would completely upset the potentiometer balance. The mixtures given are calculated from the measured gas-consumption, and the value selected for the constant. The maximum pressures are taken from the indicator-diagrams. The couples used were all 10-per-

Fig. 13.



TEMPERATURE-CYCLE OF GAS IN CYLINDER.

cent. alloys of Pt-Rh, Pt-Ir: they were as sensitive as they could be made, with a reasonable chance of withstanding the high temperature and the shock of explosion. They ranged from 0·0005 to

0·0008 inch in thickness, and projected ½ inch into the cylinder except in Test No. 4, in which the fire-clay tube was prolonged 2 inches, and the junction was 2½ inches away from the cylinder-wall.

This later method is therefore similar to that adopted by Professors Callendar and Dalby with platinum resistance thermometers, except that use is made of the comparatively high temperatures and pressures measured on the expansion stroke, instead of the much lower values on the compression stroke, where both temperatures and pressure are not more than 5 per cent. of the values at explosion.

As might be expected, within possible limits of variation of air to gas in the charge, the richer the mixture, the higher the temperature produced at explosion. Although there was no provision for timing, the maximum pressure and temperature occurred earlier as the strength of the charge increased, and for normal running with moderately rich mixtures the maximum temperatures ranged between 1,830° and 1,950°. This appears to be lower than the values generally accepted. Thus Professors Callendar and Dalby, working with a strong mixture giving a maximum pressure of about 380 lbs. per square inch absolute, calculated the maximum temperatures to be 2,250° and 2,500° in two separate experiments. In order to obtain a trial which would afford a fair comparison, the Authors made some tests with mixtures as strong as the engine would conveniently take. In one of these (G5, Table V) the ratio of gas to air was 5·66 to 1, which nearly corresponds with Messrs. Callendar and Dalby's trial with a 5·8-to-1 mixture; the maximum pressure obtained was 433 lbs. per square inch, with a maximum temperature of 2,250°, while Messrs. Callendar and Dalby obtained a pressure of 391 lbs. and a temperature of 2,500°. Their high-temperature results appear to be due to the fact that the engine was arranged to run in a rather abnormal way to give very peaked diagrams, and the values obtained here are therefore not so much in disagreement with those obtained by these investigations as would appear from a superficial examination.

A comparison of Tests No. 2 and 3 shows that the temperature of the jacket outlet does not appreciably affect the temperature of the gas during expansion, but a warm jacket appears to increase the compression temperatures. Test No. 4 refers to the long couple, and Test No. 6 to one of normal length (under very similar conditions). The temperatures are very similar for the expansion stroke, and they show a somewhat larger maximum temperature near the centre of the cylinder, as the early comparative experiments indicate. The other temperatures in Test No. 4 are high owing to the smoothing-out effect of thickening the couple. This test is included to show that even this disturbance is not sufficient to alter greatly the corrected temperatures. The results of Test No. 6 are not plotted, but they are included here because they correspond with measurements of the metal-temperatures given earlier in this Paper. The ordinary and phase-changed indicator-diagrams for the trials G 1, G4 and G5, are given in *Figs. 14* (pp. 30 and 31).

EFFECTS OF PROLONGED HEATING ON PLATINUM AND ON ALLOYS OF PLATINUM WITH RHODIUM AND IRIDIUM.

Recent researches have proved that prolonged heating causes physical changes of some magnitude in infusible metals like platinum, rhodium, ahd iridium. Sir William Crookes has shown [1] that these metals sublime at high temperatures but at different rates, and it appears probable that their crystalline structure is affected also. It is necessary, therefore, to inquire how far measurements of electromotive force taken with couples made of platinum alloyed with rhodium and iridium are affected by the prolonged heating.

This matter has been subjected to experiment up to temperatures of 1,300°, and the results show that the electromotive force of a 10-per-cent. alloy of rhodium and platinum is practically unaffected by prolonged heating. On the other hand, couples made of an alloy of platinum with 10 per cent. of iridium show a change in electromotive force when continuously heated at high temperatures. The variations obtained at 1,100° and 1,300° respectively, are shown in *Fig. 15* (p. 32),[2] and, so far as the Authors are aware, no results are available at higher temperatures. An estimate of the effects of these changes on the measurements given in this Paper must take into account that the temperature is variable, and the values given in Table V and *Fig. 13* show that the fraction of the cycle in which the temperature is above 1,300° ranges from about $\frac{1}{8}$ to $\frac{1}{18}$ of the whole period. The former figure refers to trial G5, in which the engine was run under exceptional conditions for a short time only, and the latter refers to average conditions of running.

In the absence of accurate knowledge it is probable that if the rate of change of electromotive force at these high temperatures is

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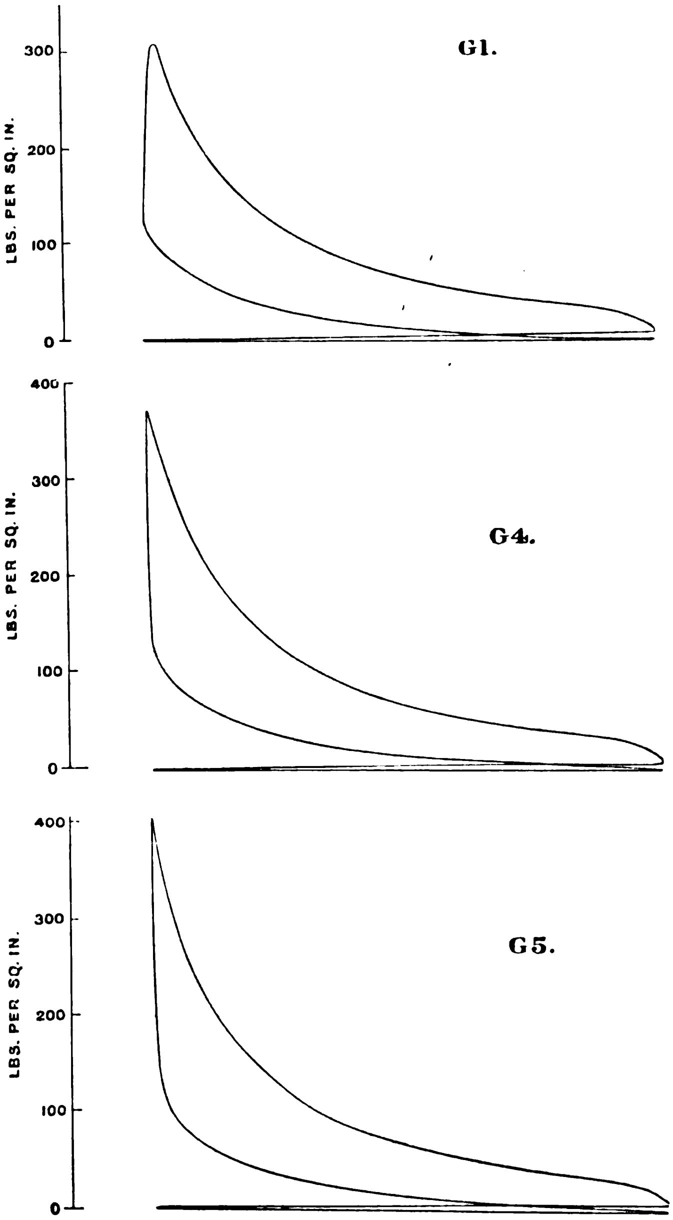
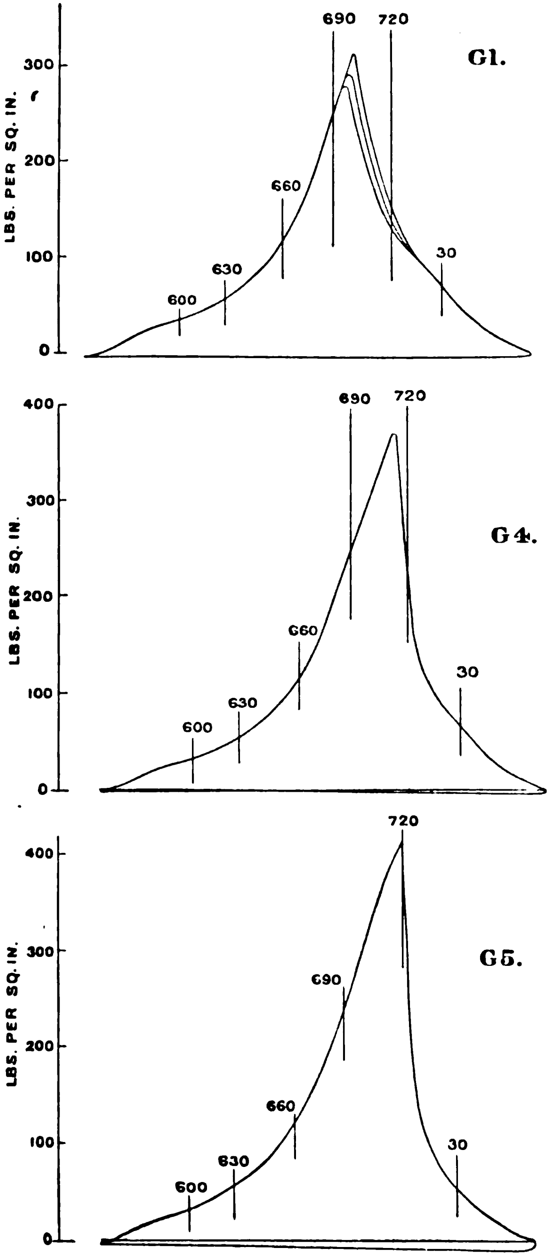
[1] Proc. Roy. Soc., Series A, vol. lxxxvi (1912), p. 461.

[2] "The Measurement of High Temperatures." G. K. Burgess and H. Le Chatelier. London, 1912.

Figs. 14.


G1.
LBS. PER SQ. IN.
300
200
100
0
G4.
LBS. PER SQ. IN.
400
300
200
100
0
G5.
LBS. PER SQ. IN.
400
300
200
100
0

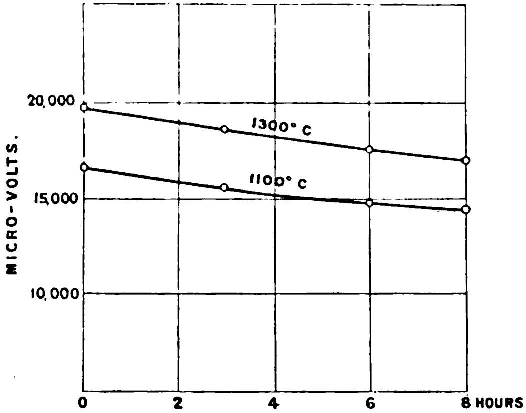
Figs. 14.


G1.
LBS. PER SQ. IN.
300
200
100
0
600
630
660
690
720
30
G4.
LBS. PER SQ. IN.
400
300
200
100
0
600
630
660
690
720
30
G5.
LBS. PER SQ. IN.
400
300
200
100
0
600
630
660
690
720
30

taken as twice that given at 1,300°, it is a more unfavourable estimate than is warranted. On this assumption, at the end of an 8-hour run under the exceptional conditions of Trial G5 the fall in electromotive force is 5 per cent., while for an ordinary trial it is less than 2½ per cent.

In no case were couples used for measurement which had been exposed for so long a time as this to the temperature inside the cylinder. The average life of these couples under such fluctuations of temperature and mechanical stress is less than this, and measurements were usually taken within at least 2 hours after the commencement of a trial.

Fig. 15.



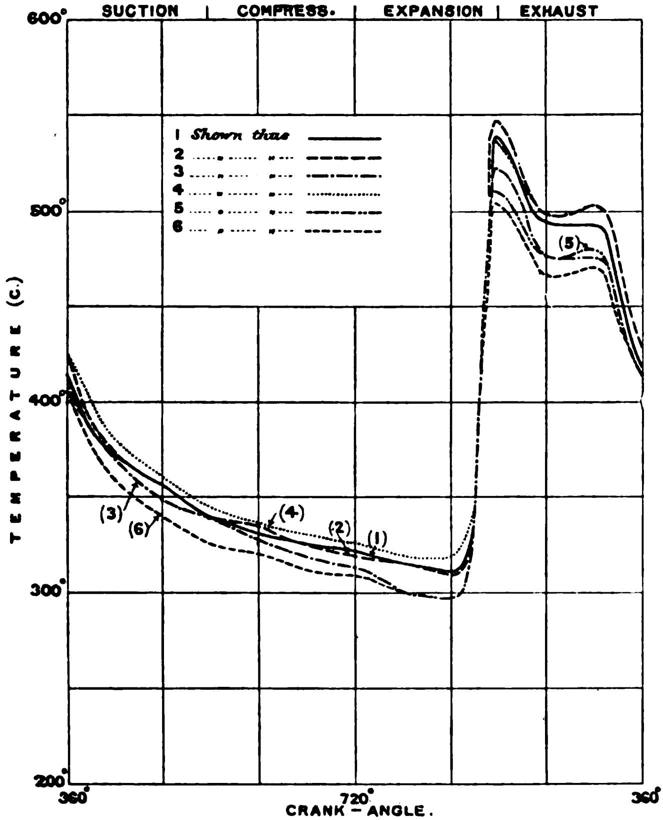
Effect of Prolonged Heating on the Electromotive Force of Pt. Rh.-Pt. Ir. Couples.

The influence of this change is therefore very small, and its effect is to cause slightly lower estimates of temperature. No corrections for this effect have been applied to the measurements given here.

Temperature of the Gas Charge at Exhaust.—It is important for many purposes to know the lower limit of temperature of a gas-engine, and especially for drawing comparisons between different types of heat-engines. The principal difficulty in measuring the temperature of the outgoing charge is due to the violent rush of gas, which causes mechanical breakage of the couple; in fact, more couples were broken in the exhaust-pipe than in the cylinder itself.

Some provisional experiments were made in 1908 at a point in the exhaust-pipe 12 inches below the cylinder-outlet, and cycles of temperature were obtained which showed that the maximum exhaust temperature is about 500° when the engine is developing 10 B.HP. and the jacket-outlet temperature is 40° to 52°. These experiments were repeated in much more detail early in 1912, and the cyclical variations of temperature obtained are shown in Table VI and *Fig. 16*, while other details of the trials are given in Table VII.

Fig. 16.



TEMPERATURE OF GAS IN THE EXHAUST-PIPE.

As the temperatures met with are moderate, a couple was used of pure platinum and a 10-per-cent. alloy of iridium-platinum, which gave a much larger electromotive force than the cylinder couples for the same range of temperature. The exhaust-pipe was tapped as near the cylinder-outlet as possible, and the couple was set in the centre of the pipe. The six tests of which particulars are given sufficiently indicate the results obtained. The values obtained during the parts of the cycle when the exhaust-valve is closed are not important, as they only indicate the temperature of the residual gases. The first (E1) was made with a rich mixture, and after the cyclical change had been obtained the charge was further enriched, and the engine was run for a time until the conditions became steady again. This change increased the exhaust temperature only very slightly, and it never quite reached 550°. The next pair of tests (E3 and E4) were intended to be for an intermediate gas charge, but the maximum pressures in the cylinder indicate that these trials nearly correspond with E1. The jacket-outlet was again cold, but in trial E3 the circulation was as supplied by the makers, with the outlet almost directly above the inlet. In this case the exhaust temperature was about 25° lower, but a change to the newer jacket circulation (E4) allowed the engine to develop rather more power, and brought the exhaust temperature back to its former value. The heat-supply was somewhat less than in the two former trials.

In the last pair of tests the outlet temperature of the jacket-water was raised to 80° or more, and the output of the engine was rather low, but little change in the exhaust temperature was produced; the measurements were, in fact, 25° lower than before. As the couple broke at the end of Test No. 5, it was thought that it might have thickened, and so have reduced the recorded temperature. A new couple was put in at once, and the test was continued as nearly as possible under the same conditions, but the values obtained were still lower by about 9°. These results showed that the temperature of the exhaust was hardly affected by the jacket-outlet temperature.

The peculiar shape of the curve showing the temperature-cycle in the exhaust-pipe may be due to something in the nature of a pulsation in the pipe. At release there is a sudden rush of gas along the pipe, which falls off until the piston moves back and expels the remainder of the burnt charge. Between the two operations there is a fall in temperature, as the diagrams show.

The result of all the variations in the conditions of running of the engine is to produce a difference of about 40° in the maximum temperature of the gases in the exhaust-pipe, which is always between 500° and 550°.

Some earlier experiments by Professor Burstall[1] with an engine of 6 inches bore, 12 inches stroke, and a maximum compression of 105 lbs., show considerably higher temperatures at exhaust.

The results obtained by Professor Hopkinson on a Crossley engine, 11½ inches in diameter, 24 inches stroke, and a compression pressure of 160 lbs. per square inch, do not enable a direct comparison to be made; but the exhaust temperature was undoubtedly higher than 500°, since the valve temperature was about 460°, and was very constant under normal conditions of running. In the Finsbury trials, the drop of temperature between the exhaust gas and the valve is about 150°, and, assuming the same difference in the large engine, an exhaust temperature of 610° is obtained, or about 60° higher than the maximum reached in the smaller "National" engine.

It may be pointed out that all the experimental determinations represent the conditions which obtain in small-power engines, but, with the possible exception of the valve and piston temperatures, they are probably applicable to much larger engines.

Briefly, the results of this investigation show that the temperature of the cylinder-liner is not more than 40° above the temperature of the jacket-outlet with an inappreciable cyclical change. The surface of the combustion-chamber may rise in places to as much as 250° with a cyclical change of 20° or thereabouts. The maximum temperature of the inlet valve is in the neighbourhood of 310° and has a cyclical change of 10° to 20°, while at the exhaust valve the corresponding temperature is 400°, with a cyclical change of 10° to 15°.

The piston of this small engine has a low maximum temperature of about 340°, with a cyclical change at the centre of not more than 80° as a maximum.

The highest temperatures of the explosive charge appear to have a limited range under normal conditions of running, and the experimental determinations show that these temperatures are between 1,830° and 1,950°.

Under very exceptional conditions the temperature may rise to about 2,250°. The exhaust temperatures appear to vary but little under the range of conditions examined here, and have a mean value near the outlet of 500° to 550°.

In conclusion, the Authors desire to express their thanks to the

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[1] Second Report to the Gas-Engine Research Committee, Proc. Inst. Mech. Engineers, 1901.

City and Guilds of London Institute for the facilities afforded for this investigation; to Mr. J. H. McDowell for his valuable assistance in the early part of the work; and to Mr. F. H. Withycombe for his skilful construction of the special apparatus required during the experiments.

The Paper is accompanied by fifteen drawings, from which the Figures in the text have been prepared.

APPENDIX.

Table I.

Date.	Gas Used.	Revolutions per Minute.	B.HP.	Temperatures Centigrade.					Plug.
				Jacket Water at Exit.	Thermometer Pockets.				
					A	B	C	D	
1908. May 13	Town gas	236	7·3	21	52	35	34·5	35	239
,,	,,	236	7·4	32	57	41	40·0	41	238
,,	,,	236	7·4	40	63	47	45·0	46	240
May 14	Producer Gas	232	7·3	38	57	48	45·0	46	179
,,	,,	236	7·8	60	82	74	68·0	66	186
,,	,,	236	7·8	87	101	93	90·0	89	188
,,	,,	236	7·8	99	108	107	102·0	101	197

Table II.

No.	Date.	Time.	Temperatures Centigrade.					I.HP.	KW.	Max. Press. Lbs. per Sq. In.
			Jacket Exit.	Thermometer Pockets.						
				A	B	C	D			
1	30.11.11	p.m. ..	21·9	49·0	35·5	35·5	35·9	..	3·2	225
2	6.12.11	3.0	74·4	84·7	78·0	75·2	72·2	..	3·52	235
3	6.12.11	3.40	89·4	95·2	86·5	85·2	82·2	..	3·47	235
4	14.12.11	2.30	60·7	74·2	60·0	59·2	57·4	..	3·4	295
5	14.12.11	3.45	66·8	81·2	64·9	63·3	62·3	..	3·9	324
6	15.12.11	2.30	29·2	63·2	44·0	45·2	44·7	..	3·72	352
7	15.12.11	4.35	31·7	70·4	47·0	48·0	48·0	..	4·12	375
8	15.12.11	6.0	71·8	89·0	69·0	68·0	68·0	..	4·0	370
9	18. 1.12	4.20	25·0	55·0	44·0	45·0	45·0	..	3·52	266
10	22. 1.12	11.15	29·4	59·0	40·0	39·5	40·0	..	3·72	296
11	22. 1.12	1.35	32·2	65·0	42·0	42·5	43·0	..	4·08	330
12	22. 1.12	3.20	34·5	69·0	44·5	45·0	45·0	..	4·06	365
13	24. 1.12	2.0	31·1	73·0	47·0	48·0	51·0	9·78	3·8	420
14	24. 1.12	4.8	31·4	75·0	47·0	48·0	49·5	10·07	4·16	440
15	29. 1.12	12.2	36·7	75·0	47·0	47·5	48·0	9·46	3·9	425[1]
16	29. 1.12	1.58	37·8	76·0	48·0	48·7	49·0	9·8	4·17	425

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[1] Water outlet at centre.

TABLE III.—METAL-TEMPERATURES.

No. .	M 1		M 1		M 2		M 2	
Date.	19.4.12		19.4.12		19.4.12		19.4.12	
Time	12.10		1.0		4.15			
	INLET VALVE. Between 2 Wires.		EXHAUST VALVE. Between 2 Wires.		EXHAUST VALVE. Wire B to Frame.		INLET VALVE. Wire A to Frame.	
	Angle.	Temp. °C.	Angle.	Temp. °C.	Angle.	Temp. °C.	Angle.	Temp. °C.
	660	13·0	460	6·0	660	325	660	182
	600	11·5	600	6·5	600	326	600	184
	540	11·0	720	5·0	480	332	480	182
	420	10·0	120	3·0	360	331	360	179
	300	8·0	240	5·5	240	327	240	175
	180	6·0	360	7·5	120	324	120	173
	60	5·0	480	7·5	720	321	720	168
	720	10·0	600	8·5	660	325	660	180
	660	15·0	720	5·25	Wire A to Frame.		Wire B to Frame.	
	Wire A to Frame.		Wire A to Frame.		660	329	660	163
	480	159	600	317	720	318	720	158
	600	160	480	320	120	320	120	164
	720	149	360	318	240	322	240	165
	120	150	240	313	360	328	360	165
	240	155	120	309	480	328	480	167
	360	158	720	307	600	328	600	163
	480	162	600	317	660	327	660	163
	Wire B to Frame.		Wire B to Frame.		Between 2 Wires.		Between 2 Wires.	
	480	146	600	305	660	6·0	660	11·5
	360	145	720	302	720	5·5	600	11·5
	240	146	120	306	120	4·0	480	11·0
	120	144	240	307	240	5·5	360	9·5
	720	137	360	310	360	7·5	240	8·0
	600	142	480	310	480	7·5	120	7·0
	480	145	600	309	600	7·5	720	11·0
			720	303	660	7·5	660	12·0
					720	5·0		

Mean Temperatures.		
M 6. 1.5.12		Temp. °C.
Inlet valve	A	311
	B	293
Exhaust valve	A	397
	B	385
M 7. 6.5.12.		
Inlet valve	A	234
	B	219
Exhaust valve	A	364
	B	355
M 8. 13.5.12.		
Inlet valve	A	233
	B	219
Exhaust valve	A	361
	B	350

TABLE III (*continued*).—PISTON-SURFACE TEMPERATURES.

Number	M 4	M 5		M 3, M 6, M 7		M 8	
Date .	22.4.12	22.4.12				13.5.12	
Time .	11.45	1.55					
				M3. 29.4.12			
Angle.	Temp. °C.	Angle.	Temp. °C.	Angle.	Temp. °C.	Angle.	Temp. °C.
Couple A.		Couple C.		Couple E.		Couple A.	
600	163	660	233	660	185	Mean	190
660	190	720	221	600	174	Couple C.	
720	180	120	211	480	169	600	294
120	150	240	210	360	180	480	294
240	152	360	226	240	158	360	294
360	122[1]	480	207	120	157	240	285
480	159	600	217	720	184	120	289
600	163	660	222	660	180	720	304
						600	297
Couple C.		Couple A.		M 6. 1.5.12.			
660	251	600	142	Couple C.		Couple E.	
600	227	480	142	600	342	Mean	191
480	222	360	160	720	364		
360	176[1]	240	141	120	323		
240	219	120	140	240	322		
120	215	720	151	360	352		
720	251	660	161	480	335		
660	255	Couple E.		600	337		
600	228	660	150	M. 7. 6.5.12.			
Couple E.		720	146	Mean Readings.			
600	157	120	139	Couple A	196		
660	177	240	140	,, C	282		
720	174	360	151	,, E	192		
120	146	480	150				
240	152	600	150				
360	138[1]	660	153				
480	151						
600	153						

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[1] Considerable variation.

TABLE IV.

6 August, 1909.		6 August, 1909.	
Crank-Angle.	Temperature °C.	Crank-Angle.	Temperature °C.
360	465	360	465
300	420	300	431
240	370	240	375
180	281	180	288
120	240	120	242
60	334	60	342
720	735	720	746
710	1,134	710	955
700	1,490	700	1,010
695	1,675	697	1,063
690	1,430	695	1,145
660	1.072	690	1,040
600	880	680	1,040
540	775	660	1,025
420	470	600	880
360	465	540	670
..	..	480	580
..	..	420	468

Revolutions per minute . .	140	140
Kilowatts	3·1	3·1
Couple . . . . . Inch	0·0006 × 0·015 × 0·5	0·0006 × 0·015 × 0·5 Partly fused

TABLE V.—TEMPERATURE OF GAS IN CYLINDER.

Number	G 1	G 2	G 3	G 4	G 5	G 6
Date	11.4.12	11.4.12	12.4.12	15.4.12	1.5.12	13.5.12
Time	11–12 a.m.	12.30–1 p.m.	..	..	..	12.25 p.m.
I.HP.	10·24	9·96	10 11	10·36	10·36	9·74
Ratio of Air to Gas	7·35/1	7·08/1	7·13/1	6·71/1	5·66/1	6·64/1
Jacket-outlet, temp. °C.	35·6	37·2	81·4	40·6	52·8	43·7
Angle.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.
360	569	568	582	705	636	576
300	496	503	515	624	540	496
240	349	348	371	517	431	335
180	256	269	317	422	371	264
120	217	223	262	365	330	213
60	228	241	273	326	337	213
30	267	275	330	339	442	278
720	..	..	..	..	2,249	..
710	..	..	..	1,947	..	..
709	..	..	..	..	..	1,925
708	..	..	..	1,889	..	..
705	..	1,848	1,871	..	1,918	..
697	1,836	..	..	..	..	..
690	1,546	1,551	1,532	1,579	1,721	1,588
675	1,423	1,418	1,397	1,437	1,586	1,450
660	1,154	1,147	1,269	1,247	1,417	1,227
645	1,159	1,124	1,136	1,193	1,275	1,140
630	1,041	1,052	1,018	1,098	1,192	1,077
615	1,022	1,007	1,017	1,058	1,124	1,071
600	1,017	975	975	982	1,068	1,030
540	856	843	816	895	889	835
480	726	708	704	794	764	702
420	648	646	637	751	705	642

TABLE VI.—EXHAUST-PIPE TEMPERATURES.

Number .	E 1	E 2	E 3	E 4	E 5	E 6
Date . .	24.1.12	24.1.12	29.1.12	29.1.12	7.2.12	7.2.12
Time . .	3.25	4.45	11.25	1.30	1.40	3.0
Angle.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.	Temp. °C.
360	417	426	411	427	421	412
300	371	..	370	379	373	357
240	356	354	348	359	354	340
180	339	340	339	345	340	324
120	331	335	329	336	333	321
60	324	324	317	330	321	311
720	322	319	313	326	319	309
660	316	315	300	320	315	300
600	311	309	297	319	312	298
570	..	..	352	..	..	..
560	..	..	..	470	..	423
550	..	523	493	..	..	466
540	533(544)	547	521	534	508	503
530	533	543	519	..	..	..
520	527	532	510	..	..	494
510	513	520	504	..	..	..
500	501	..	487	..	..	478
480	492	497	475	498	475	464
420	492	502	475	501	479	470

TABLE VII.—RESULTS FROM ENGINE-TESTS.

No.	Date.	Time.	Revolutions per Minute.	Jacket Outlet. Temp. ° C.	Ratio of Air to Gas.	Maximum Pressure. Pounds per Square Inch.	Indicated Horse Power.	Kilowatts.	Gas per I.HP.-Hour. Cubic Feet.	Heat per Minute per I.HP.	Total Heat per Minute.	Thermal Units to Work.		Thermal Units to Jacket.		Thermal Units to Exhaust, etc.	
										C.T.U.	C.T.U.	C.T.U.	Per Cent.	C.T.U.	Per Cent.	C.T.U.	Per Cent.
E 1	24.1.12	3.25	178·5	31·4	..	440	10·07	4·16	20·00	91·3	919	..	..	..	..	..	..
E 2	24.1.12	4.45	176·2	33·0	..	..	..	3·90	..	..	..	..	..	..	..	..	..
E 3[1]	29.1.12	11.25	173·5	36·4	..	425	9·46	3·90	19·29	87·4	826	..	..	..	..	..	..
E 4	29.1.12	1.30	178·0	37·8	..	424	9·80	4·17	19·05	86·4	846	..	..	..	..	..	..
E 5	7.2.12	1.40	186·0	85·0	..	380	9·33	3·78	18·53	86·7	809	..	..	..	..	..	..
E 6	7.2.12	3. 0	182·0	80·3	..	376	9·33	..	18·39	86·0	802	..	..	..	..	..	..
G 1	11.4.12	11.12	203·0	35·6	7·35/1	310	10·24	4·13	18·03	78·4	803	242	30·2	249	31·00	312	38·80
G 2	11.4.12	12.30	204·0	37·2	7·08/1	338	9·96	4·04	18·78	81·6	814	235	28·9	275	33·80	304	37·30
G 3	12.4.12	11.15	202·0	81·4	7·13/1	338	10·11	4·11	17·90	75·8	767	238	31·0	256	33·40	273	35·60
G 4	15.4.12	11. 9	204·0	40·6	6·71/1	376	10·36	4·03	19·15	83·3	863	244	28·3	320	37·10	299	34·60
G 5 M 6	1.5.12	1. 6	205·0	52·8	5·66/1	418	10·36	4·22	20·84	91·0	942	244	25·9	416	44·15	282	29·95
G 6 M 8	13.5.12	12.25	199·5	43·7	6·64/1	356	9·74	3·81	19·09	84·0	818	230	28·1	305	37·30	283	34·60
M 1	19.4.12	12. 1	200·0	36·1	..	312	10·50	4·01	17·60	77·7	815	248	30·4	256	31·40	311	38·20
M 2	19.4.12	4.15	197·5	82·6	..	322	9·92	4·04	18·25	80·6	800	234	29·2	222	27·80	344	43·00
M 7	6.5.12	11. 2	200·8	38·9	..	347	10·26	..	17·98	80·6	826	242	29·3	322	39·00	262	31·70
M 4	22.4.12	11.45	201·0	40·5	..	375	10·94	4·44	17·72	75·8	830	258	31·1	286	34·50	286	34·40
M 5	22.4.12	1.55	199·5	77·6	..	365	10·70	4·16	17·58	75·1	804	252	31·4	246	30·60	306	38·00
M 3	29.4.12	10.45	200·0	79·0	..	350	10·60	..	17·43	75·8	804	250	31·1	230	28·60	324	40·30

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[1] In trial E 3 the water-outlet was at the centre of the cylinder.

Discussion.

e President. The **President**, in proposing a vote of thanks to the Authors, remarked that it required no special familiarity with the subject to realize its great importance, and even those who were unable to appreciate fully the value of the contribution to the particular branch of science dealt with, could at all events recognize the care, the skill and the labour which had been involved in the preparation of the Paper.

Mr. Massey. Mr. W. H. **Massey** presumed it might seem to savour of impertinence on the part of a mere engineer to criticize the work of a learned professor, but hoped he would be forgiven. Page after page of the Paper contained descriptions of experiments skilfully carried out, but here and there a word or an expression occurred which reminded him of the definition once given of the lobster, as a red fish that swam backwards. A live lobster was not red; it was not a fish; and it very seldom swam backwards; otherwise the description was accurate. Why should engineers talk nowadays of heat as if it were a substance that could be put into and taken out of other substances? Surely such phrases as the flow of heat, heat flow, and quantity of heat lost were barbarous phrases, and engineers looked to the professors to help them to express themselves correctly. The Paper was full of interesting questions which it would take a very long time to deal with, e.g., why, in *Fig. 6*, the temperatures, when producer-gas was used, were higher than when town gas was used, and, as he believed, when the horse-power developed was less. Proceeding to the Authors' conclusions on p. 35, he found on reading them closely that they agreed with views expressed to him by the late Dr. John Hopkinson, at least 20 years ago, namely, that those parts of a gas-engine which were exposed to the action of gases at a high temperature were hotter than the parts not so exposed, and that the variations in temperature at any one of the different points chosen were very slight, for the reason, as it seemed to him, that there was no time for considerable variations to take place. He would like to know whether the difficulty of recording them had been overcome, because he could not find in the Paper any clear indication of records of varying temperatures taken through short periods. He would endeavour to make his meaning clear by taking the engine which was said to develop 10 HP. or 12 HP. at 240 revolutions per minute. That meant one explosion twice per second, and between those explosions there were four strokes, so that each stroke took only about one-eighth of a second. He respectfully asked the Authors to state what variation in temperature they were able to note during, he would not say one-eighth of a second, but during the whole period between the two explosions per second. By means of an indicator, variations in pressure could be recorded approximately during each of the four strokes which took place in half a second; but did the Authors know of any self-registering instruments measuring variations in temperature during such short intervals? Professor Bertram Hopkinson had conducted experiments with an engine in which the four operations—firing the charge, warming the metal, injecting the water, and evaporating it to cool the surfaces—were all supposed to happen in that order in less than $\frac{1}{12}$ second! Mr. Massey's mind was open on the subject, though it seemed to him almost impossible that so many things could take place in so short a time. He hoped the Authors would accept his remarks in the spirit in which they had been made, and he trusted that, by the alteration of a few words before the Paper was published, it would appear in the Proceedings without a blemish. Mr. Massey.

Professor W. E. DALBY observed that the members had listened to a Paper of the highest scientific interest and value. He did not think he would be far wrong in stating that this Paper, and many others that had been written on the scientific theory of the gas-engine, might be regarded as the direct outcome of a Committee of The Institution appointed in 1903, of which Dr. Unwin was Chairman. The Authors were not members of that committee, but they were members of a British Association committee which included most of the members of the Institution Committee, appointed in 1907 for the study of problems relating to internal-combustion engines. The Institution Committee held several meetings in London, and subsequently, at the instance of Dr. Dugald Clerk, it adjourned to Manchester, and there carried out a series of trials on three engines, the results of which were published in the Proceedings.[1] Every day for nearly a fortnight, during the course of those experiments, the members of the Committee at the conclusion of the day's work discussed problems connected with internal-combustion engines. For his own part he might say that those conversations had inspired the research-work which he had since done at the Central Technical College on the subject of Prof. Dalby.

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[1] Report of Committee on Standards of Efficiency of Internal-Combustion Engines, Minutes of Proceedings Inst. C.E., vol. clxiii, p. 241.

Prof. Dalby. internal-combustion engines, and work which was still proceeding. Only those who had made an attempt to measure the variable temperature in a gas-engine could know what an enormous amount of labour the Paper represented. In the first place it had to be borne in mind that in measuring the temperature in the cylinder of a gas-engine under working conditions the problem to be faced was the measurement of a temperature which might vary by 1,000° in $\frac{1}{10}$ second. The only way in which that could be done was by means of a wire fine enough to follow that rapid change of temperature without appreciable lag. The kind of wire that had to be used was illustrated in the Paper. In his own experiments at the Central Technical College he had used a platinum wire 1/1,000 inch in diameter, and the Authors used a wire of the same order, but as a couple. The outstanding difficulty in obtaining the thermometer-reading was that the melting-point of platinum was lower than the maximum temperature in the cylinder, so that when a thermometer was made which would follow the temperature, it was bound to melt the first time it was put in the cylinder. That was the kind of problem that was discussed at Manchester, and which many investigators had been trying to solve in several ways. The earlier experimenters used a thick wire, which for the time being did not take the highest temperature, which only lasted for a small fraction of a second, and therefore melting was avoided. That introduced considerable lag, and in addition the wire was not sensitive enough. The method developed at the Central Technical College was to use the finest wire obtainable, and then to screen it momentarily from the highest temperature, that was, mechanism was added so that just before the end of the compression the thermometer was withdrawn from the cylinder, an explosion then took place, and the thermometer could be inserted again at any desired crank-angle. He mentioned that method because, in conjunction with Professor Callendar, the conclusion had been arrived at that the best thermometer to use in the cylinder was the gas itself, one of the most accurately-known physical laws being that the product of the pressure and volume was equal to a constant into the temperature. It was independent of the specific heat of the gas, and it was only necessary to measure the temperature at one point in order to calculate the gas-constant, when the gas itself could be used as the thermometer in exactly the same way as the Authors had done to measure the maximum temperature. The only difference between the experiments which he had carried out and the Authors' experiments lay in the method of measuring the temperature. He had used a platinum thermometer and had made

Prof. Dalby.

the measurements on the compression-curve, because the rate of variation of temperature was the minimum there, and the measurement was therefore more accurate. The Authors had calculated the maximum temperatures from temperatures measured on the expansion-curve, where the rate of variation of temperature was very nearly a maximum. The Authors, however, avoided the correction for chemical contraction after explosion which must be made when the temperature measured on the compression-curve was used to obtain a constant from which the temperature on the expansion-curve was calculated. He was sure the Authors would not object to his making a small correction of the statement made on p. 2, that the apparatus used by Professor Callendar and himself "enabled them to measure very accurately the temperature at various points of the compression-stroke." They were able to measure temperature not only along the compression-stroke, but at any point on the expansion-curve after the maximum pressure had been passed. They deliberately preferred to measure on the compression-stroke, because the rate of variation was so much smaller. On p. 28 the Authors compared some of the results obtained by Professor Callendar and himself with their own results. He agreed with the Authors that Professor Callendar's and his own measurements of 2,500° and 2,250° were probably rather high, for reasons connected with the degree of accuracy of the indicator. When the experiments were begun, in 1907, an accurate optical indicator was not available, and during the next 2 or 3 years he set to work to make one. Eventually he succeeded, and he had brought with him the original half-plate records taken with an optical indicator, showing the extreme accuracy that could be obtained in taking indicator-diagrams from internal-combustion engines. A very light disk was used, and the pressure at the point on the compression-stroke at which the temperature was measured could be scaled off with great accuracy. Professor Callendar and he had thought that by that method a measurement of the gas-constant was obtained which gave the results as accurately as possible. The Authors by using a couple had obtained results very near to those. Professor Dalby would now like the two methods tried on the same engine working under identical conditions, to see which was really the better one for the general measurement of temperatures. The Paper included the results of a great deal of work besides measuring the temperatures of the gas itself; for instance, the measurements of the temperatures of the cylinder-walls were quite invaluable. He did not think they had ever been made before with a gas-engine. The members would

Prof. Dalby. recall the classical Paper which was read at the Institution by Professors Callendar and Nicolson,[1] giving the results of measurements made for the first time, and by the use of platinum thermometry, of the variation of temperature on the walls in a steam-engine. The present Paper gave results of measurements made on the wall-surface of gas-engines, and made under difficult and exacting conditions of working. When the former Paper was read Dr. Unwin remarked that it was a gift to engineers from the laboratory; and, personally, he thought it was not too much to say that the present Paper was another gift to engineers from the laboratory. It had added considerably to their knowledge, and although it bristled with points for comment and criticism, yet at the same time it enabled experimenters to go ahead on a solid ground of ascertained fact.

Mr. Stromeyer. Mr. C. E. STROMEYER found the Paper to be one of the most interesting to which he had listened for a long time. The methods which had been explained were certainly a revelation as to what could be done in the way of measuring the changes that went on in a gas-engine. He believed the information the Authors had obtained was far greater than that embodied in the Paper, which was clearly one of great economic value, for it would enable members to study the economic question of engines; but the Authors had confined themselves in the present Paper to the unfolding of the wonderful details of their measurements. He had tried to make a few comparisons of the pressures and the temperatures, but had experienced difficulties, which might have been accidental or might have been inherent in the experiments. Thus, in trying to measure the temperatures from the diagrams given on p. 31 he found that the ordinates were not equidistant. For instance, between 720° and 690° the distance was 8 millimetres; and for other intervals of 30° he found 6·8, 8, and 6 millimetres. He did not quite understand whether that arrangement was in accordance with some remarks that occurred in the Paper, that some regions had been drawn out; at any rate it had made it difficult for him to measure the temperature accurately, and he was not at all sure that the few figures he had worked out were correct. For instance, in trial G4, taking the total heat at the angle of 690° as a unit, he found that at 710° the heat in the cylinder was 1·3; at 708° it sank down to 1·2; at 690° it was 1; at 660° it was 0·7 and at 630° it was 0·6, so that it appeared as if there were a very considerable loss of heat. This was, of course, only imaginary, because the temperatures were measured close to the cylinder and not in the body of the gas. As to the Authors having to average the temperatures over 6° of the revolutions, he would like to point out that the readings would be fairly correct for the expansion- and compression-curve, but for the peak temperatures the mean values obtained did not give the maximum temperatures. He had not made the experiments himself, and no doubt they were exceedingly difficult, but he thought it would have been an advantage to take a larger number of average readings, say one between 6° and 720°, another between 3° and 717°, and another between 720° and 714°. By that means a better indication would have been obtained as to the probable maximum temperature than was possible by a single mean. He believed that a correction amounting in one case to about 40° C. above the figure given would have to be made. With regard to the question of the thermocouple, it was mentioned in the Paper that the couples formerly used were 1/1,000 inch in diameter, and that the results lagged very much behind. The new couples were, he understood, only 1/2,000 inch in thickness, so that he did not see that there was very much difference between the two. If the 1/1,000-inch wires were unsatisfactory he would expect that the 1/2,000-inch wires would not be quite satisfactory. It had occurred to him that the vanishing thickness of wire might be obtained by comparing two or three results with thinner and thinner wires, starting from perhaps 1/100 inch and going down to 1/2,000 inch and then extrapolating for the vanishing diameter. He thought that might be done, although he was not acquainted with all the difficulties that had to be faced. Even then there was the other difficulty, that the rise of temperature, judging by the curves, was at the rate of 20,000° per second. It seemed to him almost an impossibility for the wire to follow that temperature with anything like truth. The increase of temperature was so very rapid that he thought the wires would be considerably colder than the gases, and he did not see how that difficulty was to be overcome. Mr. Massey had asked whether there was an instrument which would record variations of temperature, and had suggested that such an instrument might be of service in experiments such as those described in the Paper. He might mention that the Cambridge Scientific Instrument Company had made a galvanometer, called the Einthoven galvanometer, which would register the change of temperature due to the pulsation of the heart. The principle of the instrument was that on passing a slight current through a very fine wire placed in a very strong magnetic field, the wire moved to the one side or to the other, **Mr. Stromeyer.**

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxi, p. 147.

Mr. Stromeyer. and by enlarging the movements a practically instantaneous diagram could be obtained. It occurred to him that even if it were impossible to use that instrument directly in the present trials, it might be possible to arrange the tension of the wire so that its vibration would be synchronized with the revolutions of the engine, and then unless the cell and the thermo-couple were balanced there would be a visible vibration of the wire. He imagined that with a synchronizing wire it might be possible to get a far finer adjustment than with a mirror galvanometer, and by that means it would be possible to reduce to a few degrees the angle over which the temperature was measured. Personally he was fond of experimenting, and he hoped that the few suggestions which he had made might be of service to future experimenters. The very large question of temperature measurement of the walls, and the question of pre-ignition, dealt with in the Paper, were of great practical value, but he would not discuss them as he had been most interested in the scientific part relating to the measurement of the temperatures.

Capt. Sankey. Captain H. Riall Sankey, referring to *Fig. 3*, desired to know whether there was any heat-resistance in the junction of the cast-iron plug at A and the body of the valve, because if there were any appreciable resistance it would increase the temperature at the point A above what would normally be there were the plug not in position. The statement was made that the quantity of heat lost in the jacket-water was determined, but although apparently no measurement was made of the loss in the exhaust, in Table VII the "thermal units to exhaust," as obtained by difference, were given. He wished to point out that at the Ashton trials to which Professor Dalby had referred, those exhaust losses were measured by special apparatus. He did not know that it had been of any particular interest to the Authors to measure them in the present case, as they had been measuring the temperatures in the cylinder, and he thought it would have been just as well to have left them alone or else measured them accurately. With regard to the Tables in the Appendix, he thought it would have been a convenience if the page on which the Tables were referred to in the first instance had been printed in the Appendix. Very often one looked first at the Tables, and then it was necessary to go back to the Paper to find out where they were mentioned. With regard to Table I, the plug temperature with town gas was about 240°, while with producer-gas it varied from 179° to 197°, a considerably lower temperature. The actual calorific value of the charge must have been practically the same, because the revolutions and the brake horse-power were practically the same. He would like to know if the Authors could

Capt. Sankey.

give any reasons for that difference in temperature. He also noticed there was not very much difference between town gas and producer-gas in the effect on the jacket: thus, when the jacket-water exit was 40° and 38° respectively, very nearly the same temperatures were present in the thermometer pockets, namely, 46° at D and 45° at C in both cases, and 47° and 48° at B. Only in A was there a sensible difference. He observed that one of the temperatures which the Authors had measured was of extreme importance in gas-engine work, namely, the temperature of the charge, but unfortunately he had not been able to ascertain definitely from the Paper what that temperature was. Thus in *Fig. 13* there were curves numbered 1, 2, 3, 4, and 5, but he was not sure to what tests those particular numbers referred. [Professor **Coker** explained that they referred to the tests G1 to G5 in Table V (p. 41).] He was glad to say they were the figures he had taken. He found that in G1 the lowest temperature was 210° C., and he would like to know if that was the charge temperature. [Professor **Coker** assented.] That was a great deal higher temperature than experimenters had hitherto been accustomed to assume for the charge-temperature in a gas-engine. The general rule, so far as he was aware, was to take that figure at about 100° C. It was quite true that it had never been directly determined before, but there was a certain amount of experimental evidence to show that 100° was not far from the truth. Even lower temperatures than that had been assumed. For example, in the Report of the Gas-Engine Committee certain diagrams were drawn in which the charge-temperature was taken at 50°, 100°, and 150°, as examples. He would therefore ask the Authors to make it quite clear that they were satisfied that the charge-temperatures were of the order of 200°. It would be seen in *Fig. 13* that some were considerably higher; for G5, for instance, the temperature was about 320°. He had thought it might be of interest to work out what the theoretical temperatures at certain points would be, and in doing so he had taken account of the variations of specific heat; in fact, he had used the results that Mr. Wimperis had deduced from the experiments of Dr. Dugald Clerk and others. To explain the method that he had used would be wearisome, but with the permission of the members he would be very pleased to describe it in a communication. The results that he had obtained were the following:—The measured compression temperature in G1 was 507°, and the theoretical 590°. The maximum temperature measured was 1,810°, the theoretical 2,350°; the release, which was somewhat indefinite in the actual diagram (*Fig. 13*), was 930°, Capt. Sankey. and the theoretical 1,490°. The theoretical figures he had given were based on an assumption with regard to the calorific value, because it was stated on p. 5 that the calorific value varied somewhat, the maximum being 280 centigrade thermal units on the 7th February, and the minimum 254 centigrade thermal units on the 12th April. He did not know whether to take the mean or what; he had therefore made an assumption, so that the theoretical temperatures he had worked out were dependent on the actual calorific value on the date when trial G1 was made, which no doubt the Authors would give him later on for the purpose of correcting the figures.[1] It would be interesting to see what the theoretical highest temperature would be in the case of G1, supposing the old idea of constant specific heat were assumed. Taking the specific heat at constant volume as 0·19 the maximum temperature was a little over 3,100° as against 2,350° for increasing specific heat. Finally, he wished to say a few words as to how the results described in the Paper might apply in the case of large engines. It had no doubt been necessary that the experiments should be made on a small engine, but he thought it must be apparent that the temperatures obtained would not be the same in a large engine. For example, he judged from what the Authors said that the charge-temperature was due in large measure to the heat in the walls of the combustion-chamber. In large engines the ratio of the wall-surface to the volume of gas was much less, and, therefore, he thought a lower charge-temperature might be expected in large gas-engines. A large gas-engine would be somewhat more efficient than the small gas-engine tested. That would, other things being equal, increase the maximum temperature; but, on the other hand, if the charge-temperature were lower, that would lower this temperature. On the whole, he thought possibly the maximum temperature would be slightly lower. The foregoing had reference to the temperatures of the gas itself: the metal-temperatures in large gas-engines would no doubt be much higher, especially in certain places like the middle of the piston.

Dr. Unwin. Dr. W. C. Unwin, Past-President, commended the Paper as the result of a research involving great patience, and carried out with competence and much ingenuity. The results were a series of exact determinations in the conditions under which the experiments were made. Those results did not easily lend themselves to discussion. They were valuable, however, because they were avail-

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[1] The Authors having done this, the figures now given are the corrected theoretical temperatures.—H. R. S.

Dr. Unwin.

able for use as occasion arose, and they would serve to divert engineers from some attempts at modification of the gas-engine which it appeared would not be profitable. Professor Dalby had alluded to the fact that in speaking on a Paper by Messrs. Callendar and Nicolson dealing with an analogous subject, Dr. Unwin had used the phrase that it was a gift from the laboratory to the profession. That Paper related to the determination of the temperatures in a steam-engine cylinder. Its result was very largely to modify current views on one of the most important of the losses which occurred in the action of the steam-engine. Thirty years ago Hirn had shown that there was a discrepancy, amounting to 30, 40 or 50 per cent., between the rational theory of the steam-engine and the results of experiment, and that that was due, largely at any rate, to the effect of the conductivity of the cylinder-walls. The Paper of Messrs. Callendar and Nicolson showed that, in part at any rate, the missing quantity—the difference between the steam shown by the indicator-diagrams and the steam which entered the engine—was due to another cause. That very fundamentally altered the views of engineers. It was not often that a research happened upon a result of so much importance. The present Paper could hardly claim to be in that respect so important, but it was a very useful one, for which The Institution would be grateful to the Authors. He remarked the ingenuity of the form of thermo-couple which the Authors had used in determining the temperatures on the surface of the cylinder. The first thing that struck him about the Paper was the low temperature at the interior of the cylinder-wall and its small cyclical variation. The temperature at the exhaust-valve and that on the surface of the piston were very much higher, and that was known practically, because in almost all large engines it had been necessary to water-jacket the exhaust-valve, and in most cases to water-jacket the piston. But for other parts the temperatures were, he thought, perhaps lower than would have been expected. Relatively to the temperatures in the cylinder they were very much lower than in the case of the steam-engine, and no doubt that was due to the fact that steam parted with and abstracted heat from metal surfaces enormously quicker than permanent gases did. The fact that there was such a small temperature-gradient through the cylinder-walls was perhaps an explanation of why comparatively small variations in the jacket-temperature had such an effect on the working of the engine. One important point put forward in the Paper was that the rise of temperature of the metal in the inlet-pipes had a large effect on the temperature of the charge, and so limited the power

Dr. Unwin. of the engine. He thought that was expressed a little too broadly in the Paper. The result was no doubt right, but the generalization should have been confined to small engines. It was pretty clear that in larger engines, where the volume passing through the passages was very much greater in proportion to the surface of the passages, the effect largely disappeared. One of the most interesting points in the Paper was the direct determination that had been made of the temperature of the gases at explosion. That temperature had been determined before by Professor Dalby, by measurements taken along the compression line. The Authors had determined the temperature of explosion directly by a thermocouple, and indirectly by measurements taken along the expansion line. It was possible in the case of the direct determination that the lag of the thermo-couple might have made the temperature appear somewhat lower than it really was. It appeared that the temperature of explosion determined from measurements along the expansion line was lower than that found by measurements on the compression line. There was one action to which no reference was made in any Paper on gas-engines he had ever seen, namely, the possible action of the piston leakage and valve leakage on the determination of the volumes in the cylinder. It was rather to be expected that, if there was piston or valve leakage—and he supposed there must be some, although he did not know how much it was—the effect would be to lower the temperatures determined by measurement on the expansion line compared with the measurement on the compression line, because one was after and the other before the greatest pressures in the cylinder and the greatest probable leakage through the piston and valves. He merely threw that out, first, as a possible explanation of a discrepancy, and secondly, because he thought that, in proceeding in that way to determine the temperatures in the cylinder, the action of possible leakage had been overlooked. In reading the Paper he had been struck with the fact that there was some discrepancy between the results of the Authors' experiments and the experiments carried out by Professor Hopkinson at Cambridge on an engine two or three times as large. That seemed to indicate that the size of the engine had no inconsiderable influence on the results of measurements of the kind with which the Authors were dealing. Unfortunately all the experiments hitherto made of the kind described in the Paper—attempts at accurate measurements of temperatures—had been made on small engines, and mostly on engines using illuminating-gas. For such engines the form was standardized: there was not

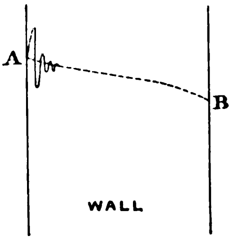
Dr. Unwin.

much more to be done with them; engineers had probably arrived at a point beyond which no sensible improvement was to be expected. At any rate, it was not to those engines, but to large engines using coke-oven gas and producer-gas, that they had to look for a large influence in engineering. The centre of interest in regard to gas-engines had completely moved, since the days when Dr. Dugald Clerk began experimenting, from the small engine to engines of large size. The fact that, even in the engines described in Professor Hopkinson's and the present Papers, the size seemed to have an important influence, showed that the results obtained by the Authors must not be applied, without great reserve, to the action in larger internal-combustion engines. It could easily be seen that, in the really large engine, nearly all the conditions of working were somewhat modified. The influence of the jacket was much less, due to the smaller area of the jacket compared with the volume in the cylinder; the strength of the charge in the large engine was different; the gas used was different; and the speed of revolution was much lower. The effect of the lower speed of revolution was that the very hot gases were much longer in contact with the wall, and therefore the results given in the Paper could not be applied in any exact way to the action of the large engine. He was very sorry that, up to the present time, no one had ventured to make anything like accurate experiments on really large engines. There was no doubt that useful information could be obtained in the case of large engines if experiments were carried out by the methods described in the Paper.

Mr. Wimperis.

Mr. H. E. **Wimperis** said that the Authors had measured two things—the temperature in the gas and the temperature in the metal. They were the first persons to succeed in measuring the temperature of the gas at or near the crest of the explosion-wave, and they deserved the congratulations of The Institution for having achieved that difficult piece of work. A good many people had measured the temperature in the walls, so that besides the Authors' results there was a body of other experimental data dealing with that subject, which proved two things conclusively: first, that the gradient through the cylinder-walls was steady, and secondly, that the fluctuations were confined to what might be called a skin thickness. If, in *Fig. 17*, the line A B represented the temperature-gradient through the metal wall, that

Fig. 17.



Mr. Wimperis. line was straight. The temperature-gradient was practically independent of time, and did not change unless the load or the temperature of the water changed. Superposed on that line there was a ripple at the surface which was represented in a highly exaggerated manner in the Figure. It died out within a very short distance of the surface. The Authors had shown that the range at the skin was very small, of the order of 10° as a maximum. Therefore the temperature-gradient might be regarded as quite unconcerned with fluctuations in temperature in the gas, and in thinking of the ripples it was not necessary to consider what was happening to the line A B on which they were occurring. An analogy which it was interesting and useful to bear in mind was that of the surface of the earth, where a similar thing occurred. There were in that case, however, two ripples due to external heating and cooling, one a quick ripple, due to change of temperature from day to day, and the other a ripple of longer period, due to seasonal changes. These ripples were confined to the surface of the earth, just like the ripples in the gas-engine wall. In the case of the earth, the interesting fact occurred that a short distance below the surface the temperature was practically constant, so that in summer it was found to be lower and in winter higher than the temperature at the surface. The daily and seasonal ripples were confined to so small a thickness of the earth's crust that at a depth of, say, 100 feet the temperature was sensibly steady. The Authors showed in *Fig. 6* the way in which the steady temperature varied along the wall. The flow of heat through the wall of a cylinder was generally pictured as being a flow from one side to the other, but it was not entirely so. Some of the heat went along the wall, and that, as the Authors showed by their diagram, was a very important point. In *Fig. 6* there was a sideways temperature-gradient represented by the slope, and that temperature-gradient was proportional to the heat-flow along the wall. Therefore there was at the hot end of the cylinder not only a radial flow outwards to the cooling-water, but also a flow along the wall and then outwards to the cooling-water. The Authors had found that when there was a very effective stream of water surrounding the jacket the heat did not go out very nearly radially. It had always to be borne in mind that although there was a temperature-gradient across the wall it was not the only gradient; there was also a gradient along the wall, and it was possible to picture the heat rushing along the barrel and getting out farther along, where the water was cooler and where the actual wall was also cooler. With regard to the piston temperature, 12 years ago Professor Burstall, of Birmingham, made

Mr. Wimperis.

a series of tests upon gas-engines at the instance of the Institution of Mechanical Engineers, and in the second report of the Research Committee[1] of that Society he gave the result of a great many different measurements that were made on temperatures, pressures and volumes in gas-engines. Professor Burstall had not measured the temperatures in the exhaustive way the Authors had done, but from the figures that were given of pressure and volume on the indicator-cards it was possible to calculate how the heat was flowing from the gas at different portions of the stroke. Professor Burstall did not give that calculation, but gave data on which it could be made. On going through the calculation on his own account subsequently, Mr. Wimperis found that at the end of the compression-stroke the gas was always receiving heat. That was a surprise to him, because the gas at the end of the compression was at a temperature of 400° C., or even 450° C., and therefore substantially hotter than the walls and likely to cool rather than to gain in heat. On working it out, however, taking into account the then newly-considered variability of specific heat with temperature, he found that the gas was receiving heat. He put that down to the high temperature of the piston-face. The results were first published in *Engineering*.[2] By that backward method he had deduced that the temperature of the face of the piston must be in the neighbourhood of 500°. No measurements of it had been made at that time, but the results of the Authors' experiments, and of other experiments that had been made in the last few years, bore out that early deduction. Mr. Wimperis had found that the temperature of the face of the piston must be in the neighbourhood of 500°, and that at the end of the compression-stroke, when the gas was in a relatively thin slab, that high temperature of the piston-face had a heating effect upon the gas substantially greater than the cooling effect of the walls, and that this net effect was detectable by a close analysis of the indicator-diagram. Until lately engineers had been accustomed to picture the use of cooling-water round a cylinder as essential for the purpose of the cooling of the cylinder-walls, but now it was necessary for them to think differently. In small engines of about the size used by the Authors, or a little smaller, the cooling-water around the combustion-space was certainly necessary for the cooling of the walls, but along the barrel of the cylinder the cooling-water was not for the purpose of cooling the walls, but for the purpose of cooling the piston.

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[1] Proc. Inst. Mech. E., 1901, p. 1031.

[2] Vol. lxxiii (1902), p. 833.

Mr. Wimperis. That was discovered during the very interesting discussions that took place at the meetings of the Gaseous Explosions Committee of the British Association. It was discovered in the following way:—The radiation from a gas was proportional to the absolute temperature raised to the fourth power. There was shown in *Fig. 13* (p. 27) a great rise of temperature, but that rise was nothing like as great as the rise in the radiation, which went with the fourth power of that rising curve. Therefore the radiation loss just after the moment of explosion proceeded at an extremely high rate, and almost the whole of the heat that was going to get away from the gas at all got away then. That meant that in the explosion-space there was an enormous loss of heat owing to surface-cooling and radiation, but chiefly to radiation. When the piston moved the temperature fell, and the fourth power of the temperature had no longer so considerable a value, so that during the stroke hardly any heat was lost by radiation to the walls. Those who were interested in the subject could refer to the Fifth Report of the Gaseous Explosions Committee for details. Professor Hopkinson had been able to make a good-sized engine of, he thought, 2½ feet diameter without any water circulating round the barrel at all. The purpose for which, in small cylinders, the water circulated round the barrel was to keep the barrel cool, in order that it might cool the piston; but in a bigger engine, in which there was a water-cooled piston, it was not necessary to cool the walls for the purpose of cooling the piston, because the heat-flow along the wall was sufficient to make up for the slight loss of heat that occurred during the actual expansion-stroke. The work of the Gaseous Explosions Committee, to which he had referred, should be known to every person interested in the subject of internal-combustion engines.

Dr. Harker. Dr. J. A. **Harker** remarked that the Authors had done what many people would have considered almost impossible. They had used a thermo-electric method employing couples to determine temperatures up to the very highest measurable by couples. To accomplish that they had not had the usual kind of equipment, namely, a galvanometer connected with the potentiometer during the whole time, but they had only had connection between the measuring instruments on which the balance was made and the couple circuit itself for the one-hundred-and-twentieth part of the whole time of the cycle. Unless a balance method had been used, he thought the Authors would not have obtained any results worth naming. For the couple they used platinum-iridium against platinum-rhodium, giving a sensitiveness of 3 to 4 microvolts per degree up to the high temperatures. Therefore, the sensitiveness of the

Dr. Harker. apparatus was diminished, not only on account of the type of contact, but inevitably on account of the alloys chosen. The couple itself was necessarily of an insensitive type, and the Authors had accomplished an extremely nice piece of physical measurement in using that method at all. He was pleased to see that Johnson-Matthey standard alloys had been used. Ten years ago, or a little more, the confusion with regard to the question of thermo-couple alloys was great. A firm would order an alloy which it was said contained 10 per cent. platinum-rhodium, and would use that against a wire which was called pure platinum to form a thermo-couple, from which a certain electromotive force at a certain temperature was obtained. After the arrangement had been fixed up, and had worked satisfactorily for a time, for some reason or other the couple broke down; and another piece nominally of the same composition was ordered. But it was seldom that a wire giving similar results was obtained. Couples had passed through his hands which showed that the temperature differences obtained under those conditions could be as much as 300° to 400° at 1,000° on two wires said to be of the same composition. Ten years ago it was suggested to the late Mr. George Matthey that it would be a very good plan if, in the light of that experience, instead of making a small quantity of alloy at a time, a large ingot were made from which people using couples could be supplied, with reasonable prospect of their getting a homogeneous alloy. Mr. Matthey took up the question, and made a large ingot of 400 oz. of pure platinum-iridium. The present was a good opportunity to say a word on the introduction of platinum-iridium as opposed to platinum-rhodium, a question on which a good deal of nonsense had been published. Most people who employed a thermo-couple had platinum on one side of the couple and an alloy on the other side, and up to the time to which he was referring Le Chatelier's platinum-rhodium alloy was in general use. But platinum-rhodium was at that time notoriously impure, and very difficult to get homogeneous. Most of the platinum-rhodium alloys sold 10 or 15 years ago contained up to 3 per cent. out of 10 per cent. of rhodium which was not rhodium at all. That influenced considerably the electromotive force given by an alloy of a certain nominal composition. On the other hand, it was possible to prepare iridium pure and of a high degree of homogeneity, as had been done by Messrs. Johnson and Matthey. He had recommended Mr. Matthey to use Tait's original 10 per cent. platinum-iridium alloy instead of rhodium, partly on account of its easier metallurgy and partly because up to 1,000°, though not beyond, the use of iridium

Dr. Harker. instead of rhodium was advisable, owing to its giving about 1½ times the electromotive force of the rhodium alloy; and there was no reason why platinum-iridium should not last as long as rhodium, provided 1,000° were not exceeded. If 1,000° had to be exceeded, it was desirable to use rhodium for other reasons. Large ingots of rhodium alloy had since been made by Messrs. Johnson and Matthey. A thermo-couple used in any way in a gaseous atmosphere gradually degenerated to some degree, because of the effect alluded to by the Authors, which had recently been emphasized by the experiments of Sir William Crookes—the volatilization of the iridium; but nearly all couples broke down on the side not of the alloy but of the platinum. The weak thing in the ordinary couple was the platinum side. The Authors in their experiments had eliminated the pure platinum altogether. He thought that was an interesting point in connection with the metallurgy of those alloys and their use in thermo-couple work. The question of the volatility of the various constituents in an alloy of that kind was interesting. What happened when a refractory metallic wire was heated to a high temperature was occupying a great deal of attention at the present time, as it had an important electro-technical application to the problem of the production of a ½-watt lamp. The method of stopping the disintegration of the surface of metals when they began to emit first positive and afterwards negative electricity had been the bugbear of the lamp-maker; but lately those difficulties had been largely overcome, and the possibility of a ½-watt lamp working at a much higher temperature than the ordinary tungsten lamp using about 1 watt had been demonstrated. It had been done in the laboratory, but had not yet arrived at the commercial stage. Large units of that type had been shown having a life of about 1,000 hours. He wished to suggest to the Authors that it was possible at the present time to get wires of tungsten and tantalum which would be most useful for such high temperatures as they were working with. If the Authors wished to go higher still and put the wires into places where the temperature of the gas at explosion was too high for platinum-iridium and platinum-rhodium, they might use a tungsten-tantalum couple, or possibly one of tungsten-molybdenum. He was not prepared to say what the sensitiveness of those wires was at the temperatures referred to in the Paper, but he thought a wire could be obtained which would last for a time at all events, under the conditions of the explosion, and which would not melt. The melting-points of both tungsten and tantalum were 1,000° higher than the maximum of the explosion. The Paper mentioned that the platinum-iridium and platinum-rhodium couple melted and hung together. In some experiments he made a good many years ago, employing a little furnace in which the furnace tube was a hollow tube made of rare earth—material very similar to what was used in the Nernst-lamp filament—he used an arrangement for determining the melting-point of platinum. If the furnace was heated by passing a current through the tube, what happened very often was that if wires not too thick were used, the iridium wire remained intact while the platinum melted gradually: a drop of molten platinum gradually ran up the iridium wire, and a hanging drop was formed from the platinum bridging across to the other wire. He had obtained that result several times, and it reminded him that in the melting of a wire like that he referred to, the surface tension of the molten metal was so great that it would hold up for a long time. Mr. Stromeyer had suggested that it would have been possible to use an Einthoven galvanometer, the suggestion being that the Authors could have mapped out the whole course of the cycle by making the galvanometer period extremely short and dispensing with the contact-maker. That would have been feasible if it had been possible to ensure that the damping of the instrument was satisfactory, and that the proportionality between the deflection and the current would be anything like what was wanted. In working on an open scale, with the spot going backwards and forwards 100 times a minute, there would have been some considerable difficulties, and Dr. Harker did not think the use of the Einthoven galvanometer would have been possible in practice. One speaker had suggested the possibility of following very rapid alternations of temperature with couples. An illustration of how a filament would follow to some extent very much more rapid alternations than were present in the case under discussion was afforded by the familiar example of an ordinary glow-lamp on a power circuit. If an ordinary tungsten lamp were put on a power circuit where the alternating supply was at 25 cycles instead of the more usual 100 cycles or so, the pulsations of the lamp could be seen quite markedly, even when the filament was fairly thick. The frequency was very much higher than in the case of the gas-engine. Dr. Harker.

Mr. E. J. Davis referred to the observation of Captain Sankey that the temperature of the in-charge was much higher than he had expected. There was one good reason for that fact, namely, that in the type of engine used the air-seating was bolted to the back of the cylinder and was not jacketed at all. It also had an asbestos joint between the cylinder and the air-seating, so that Mr. Davis.

Mr. Davis. everything was very hot. In the engine experimented upon by Professor Hopkinson at Cambridge the air-seating was a part of the water-jacketed cylinder, and it was not parted by any joint at all. That, of course, made a considerable difference. In the engine which the Authors had been experimenting upon it was impossible to put the hand on any part of the seating, whereas in the engine upon which Professor Hopkinson had carried out his experiments Mr. Davis had no doubt the hand could be put on the air-seating while running at full load, or, in fact, any load. The Paper stated that the engine used was a standard engine, but he did not remember having seen a piston with bevelled edges such as was shown in the diagram, and he thought they were rather unusual. It would have the effect of giving a higher temperature in the centre of the piston, because there was a much larger surface to receive the heat. He was surprised that no diagram had been taken with a weak spring, say a 1-in-10 spring, to show the pressure during the suction stroke and during the exhaust stroke. Mention was made of a diagram of a 1-in-40 spring, but not of a weak spring. From *Figs. 14* on p. 30, G1, G4 and G5, it seemed that the engine was running with a good deal of back-pressure, which would be plainly shown with a weak spring. Back-pressure meant that possibly the engine was left with a greater weight of the products of combustion in the cylinder for the next charge, and that had a considerable effect upon the initial pressure and naturally on the temperature. It was quite possible to get an engine with an initial pressure of 400 lbs. per square inch, and still not get a mean pressure of 40 lbs., due to the high temperature at which it ignited. He was recently testing a two-cycle oil-engine which had been used with great success in India and for which it was thought there was possibly a market in England. Although the engine had given satisfaction when used on irrigation-works in India, it had never been properly tested. As there were no means of putting an indicator on it, he had suggested the advisability of coupling the engine to a dynamo so that it could be run at various loads, when it would be possible to see what it would do. But he found that the engine would give more power when running at 160 revolutions per minute than when running at 240 revolutions per minute, so that he had to find some means of putting an indicator on to ascertain the reason. It was obvious that the engine was not scavenging at all, or only slightly. Probably one-third of each charge consisted of exhaust products which should have been scavenged. The initial pressure was about 400 lbs. per square inch, and the mean pressure worked out at

Mr. Davis. 25 lbs. That of course was absurd: but it showed how the exhaust products would affect the initial temperature and the pressure. With reference to the gas-supply of the engine described in the Paper, he noticed that no experiments were made until it had been running for a considerable time, so that it had a fair temperature throughout. On many occasions he had noticed that a considerable difference was obtained in the quantity of gas per charge when running on a low load as compared with full load, due to the expansion of the gas-valve spindle. He knew of a case in which the voltage of a dynamo driven by a gas-engine dropped, after running for an hour on full load, 15 or 20 volts, simply because the gas-valve spindle had expanded so that the engine was taking in too much gas: it was really choking itself. He presumed that, in the experiments described in the Paper, the gas-consumption had been measured under normal conditions. It would cause a variation in the card taken during load if the gas-valve on the engine were on the non-jacketed part of the seating he had previously mentioned. The temperature of the exhaust-valve depended closely upon the point of ignition. He had recently been experimenting on a 250-HP. engine, and found he could boil water with the ordinary working supply in the exhaust-valve if there was a lead on the ignition of only 2 inches. The firing was so late, and it got the exhaust-valve up to such a high temperature, that no water could be got in the exhaust-valve, it was making steam so fast. He had tested engines with late ignition which had been running with such late firing that the exhaust-pipes became red hot due to the late firing. Design also affected the temperature of the exhaust-valve. About 18 years ago he was experimenting upon a 100-I.HP. engine—what was then considered a large engine. In the first case he had an exhaust-valve which weighed 6¾ lbs. The engine would run on full load for 20 minutes without any sign of pre-ignition, but after that it would pull up within 2 or 3 minutes owing to pre-ignition. He put in a new valve weighing 10 lbs., the metal being put on the valve in the form of an inverted cone under the head, and he was then able to run the engine for 1 hour and 50 minutes without any pre-ignition occurring. The reason was fairly simple. The heat was conducted from the head to the gland, and if sufficient area were given for conducting the heat the temperature could be kept down sufficiently to run the engine. That was a point which was often missed in engines at the present day. The head was like a flat disk fixed upon a round spindle, so that there was little or no metal for carrying heat away from the head. Another point

Mr. Davis. which affected the temperature was the seating of the valve. Mr. Atkinson, in his "Cycle" engine, put very wide seats on the exhaust-valve, and that had a considerable effect in keeping down the temperature of the valve, because the exhaust-valve was exposed to the hot gases, working and exhausting strokes, for, say, 220°, whereas it was on its seat for 500° of angular motion of the crank. If sufficient surface were given, and the seat of the valve could be kept cool enough, a large amount of heat could be abstracted from the exhaust-valve while it was on its seat. He was much surprised to read that there were no signs of pre-ignition in the engine when the Authors tried to measure the temperature in the centre of the combustion-chamber, using a clay tube. It was rather extraordinary that the engine should be able to run with a clay tube in the centre of the combustion-chamber. There was a simple way of obtaining pre-ignition. If a piece of asbestos were suspended on a wire in the centre of the cylinder every possible phase of pre-ignition could be obtained. He thought he was the first to give a diagram showing that.[1] It was rather an interesting diagram; he had never been able to obtain one like it since. With reference to the question of the combustion-chamber, the Authors seemed to think it was a mistake to have the water circulating so that it did not go fairly through the combustion-chamber. He did not think that was a mistake, because the engine was not always working at full load, and if the engine was being worked at anything under full load there was an economical advantage in running the cylinder hot.

The Authors. The AUTHORS, in reply, desired to express their great appreciation of the very kind remarks which had been made in the course of the discussion. They also desired to express their great regret that Dr. Dugald Clerk, who had taken much interest in their experiments, was not able to be present, through illness. Mr. Massey had referred to the manner in which they had written their account of the experiments, and had called the language unscientific. The Authors did not think he could fairly bring that charge against them, because, on referring to Papers by such eminent scientific men as the late Professor Tait and others, language of a similar, in fact of an identical, kind was used. Had Mr. Massey charged the Authors with obscurity in what they had said, they would have felt it was a much graver matter; and they thought it quite possible that had they used terms other than those which had been used, the charge of being pedantic might have been made against them. Another point which Mr. Massey raised was, whether it was possible to measure the change of temperature in the engine between one explosion and another. It was hardly necessary for them to say much about that point, because the Paper showed that these measurements could be made with ease; and as Dr. Harker had pointed out, the 12° interval which the engine was turning through was sufficient for a measurement of the temperature at some particular point, and corresponding with about $\frac{1}{120}$ second. Another point which had been raised was the amount of variation which could be detected under those conditions of experiment, and it was fairly evident that the amount of variation of temperature which could be detected was only limited by the melting-point of the couple. Professor Dalby had called attention to the important influence which the Institution Committee, and subsequently the British Association Committee, had exerted upon research relating to gas-engine phenomena, and the Authors desired to say how much they were indebted to those Committees. They were glad Professor Dalby had brought out the point that the measurement of temperature could be made with a platinum thermometer on the expansion side, because they had unintentionally omitted to say they were aware that those measurements could be made. Professors Callendar and Dalby had not made use of measurements of that particular kind, because they considered that the lag might cause an error. It would be very interesting to follow out the suggestion that the two methods—the thermo-couple method and the platinum-thermometer method—should be tried on the same engine, in order that the experiments might determine whether there was any real difference between the temperatures which were obtained from the one and the other. At present there was a gap between them of about 250° C. for the explosion temperature; but, as Professor Dalby had indicated, this difference was probably due to the optical indicator and not to the thermal measurements. Mr. Stromeyer had drawn attention to the fact that the temperature at the top of the explosion curve could not be determined by measurements in which the average value was taken for the time in which the circuit was closed. That point was brought out quite clearly in *Fig. 18* (p. 66), in which the G1 diagram had been drawn afresh. The measurements on the expansion side were shown, and also the values calculated for the peak of the explosion curve, so that really no use was made of a measurement right at the top. The Authors made such measurements at the commencement, and *Fig. 18* showed that the value of the temperature which was actually obtained was about 1,675° C.; and the couple The Authors.

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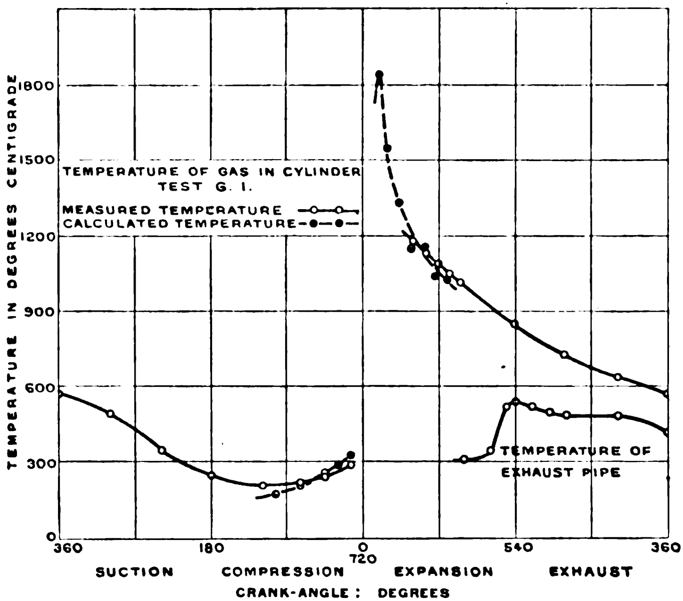
[1] *Mechanical World*, 3 November, 1894.

The Authors. fused a little while afterwards in the same trial, thereby showing a maximum value of about 1,850° C. It was evident there was a very considerable amount of lag just at the top of the explosion curve, and they ultimately came to the conclusion that it was better to take the temperature along the expansion curve as high as they dared go and then extrapolate a little to get the maximum temperature by means of measurement of pressure, volume and temperature, using the constant *pv/t*. With reference to the possible effect of heat-resistance in the cast-iron plugs used in measuring surface temperatures, the Authors did not think that any appreciable difference was caused by heat-resistance, since the plugs were all one piece of metal and had ample surface contact. The data relating to measurements of the heat in exhaust gases were given merely for the purpose of general information, and had this side of the work been pursued further the Authors had intended to use Dr. Clerk's method of analysis, which gave the heat in the gas at the end of expansion. The surface temperature of the combustion-chamber was found to be low with producer-gas, and this might possibly be due to low ex-

Fig. 18.

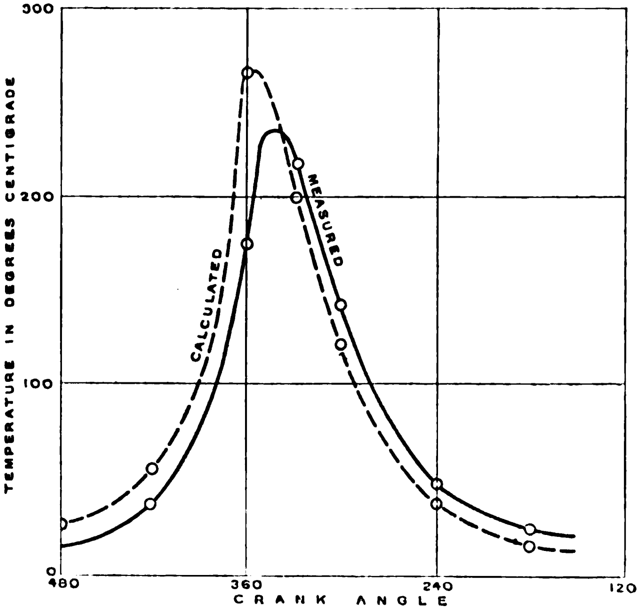


The Authors.

plosion temperatures and the smaller effect of radiation corresponding therewith. As to the suction temperature, it was hardly necessary to point out that calculations gave a low value which merely took into account the mixing of the fresh charge with the residual gases, but this left out of account several factors of importance. Two of them had been indicated in the discussion, namely, the heating of the incoming air owing to the high temperature of the unjacketed air seating, and the effect of back pressure, which increased the weight of the residual gas. There was also the effect of conduction and radiation of heat to the gas, due to the hot walls of the combustion-chamber and piston. All these conditions tended to raise the suction temperature, but the Authors thought that the measurements of suction temperature were higher than the mean temperature of the charge because the effects upon the couple of lag and radiation from the hot walls both tended to give high measurements of temperature, while, in addition, the somewhat stout couples used to avoid melting with rich mixtures also tended to give high measurements on both suction and expansion lines. The effects of lag and radiation from the walls were opposed during expansion, and the measurement of pressure, volume and temperature along this line afforded an independent means of calculating the temperature before explosion; and, as shown by *Fig. 18*, there was good agreement between experiment and calculation for the last part of the compression line, tending to a value of the suction temperature of 150° for an average mixture, and higher values with rich charges like those of trial G. The question of lag had been raised by several speakers. It was impossible to deny that there must be some lag in the measurement by thermo-couples, but the Authors did not think it was very large. They had come to that opinion first as the result of some experiments they had made, one by motoring the engine round to compress and expand the air in the cylinder. For example, in one experiment the thermo-couple used was a thick one, that was, about $\frac{1}{100}$ inch, and on the test in the motoring experiments the air was fairly dry—the test being made in July, and the difference of temperature between the wet and dry thermometers being about 3°, which meant that there was a small amount of moisture in the air. The results obtained showed the amount of lag which occurred, although the temperatures did not agree, because of the moisture in the air. The dotted curve in *Fig. 19* showed some of the calculated values of temperature, and the plain curve showed the observations which the Authors were able to make. If the two diagrams were compared it would be seen that on the compression

The Authors. side the angle of lag was under 10°, and for the expansion side it was about 5°. Afterwards the Authors made experiments upon much thinner couples, about $\frac{1}{2000}$ inch thick, and obtained values which indicated that the lag was not a serious matter. This was more clearly demonstrated by *Fig. 19*, where the Authors had given the measured values of suction temperature, and had also made a calculation from the measurements on the expansion line, allowing for the contraction on explosion. They made this considerable step and found that the temperatures were as shown in the diagram, thereby indicating in another and distinct way that the lag for the couples $\frac{6}{10,000}$ to $\frac{8}{10,000}$ inch thick could not have been a very serious matter. Professor Unwin had suggested other very interesting points in the course of his remarks, and one of these related to the question how far the Authors' results on a small engine were applicable to large engines. This was a difficult matter on which to express a positive opinion. Professor Hopkinson's results on exhaust-valve temperatures seemed to show a very fair agreement, and for the same strength of charge it seemed probable that the temperature of explosion in a large engine might not be very different from that in a small one. The

Fig. 19.



The Authors.

other factors mentioned would no doubt have a considerable influence, but their magnitude could only be definitely determined by actual measurement. Leakage was another very important point, but it would be seen from *Fig. 19* that the time rate of change of volume which occurred between the top temperature and the temperature at which they measured was so small that there was little chance for a leak to occur. In the earlier measurements, where they actually measured the top temperature without any calculation whatever, it could not make any difference at all. If there were any appreciable leakage past the piston it would in general upset the results obtained from the tests. For instance, the experiments of Dr. Dugald Clerk, in which he cut out the valves and allowed the charge to expand, and then re-compressed and re-expanded it, would not have given accurate results if the leakage had been at all appreciable, and the fact that he obtained such good results showed that the piston of a gas-engine could be made so as to reduce the leakage to a very small quantity. In the experiments described in this Paper the Authors had, in a very indirect way, a confirmation that the leakage must be very small, because on reference to p. 26, on which the values of PV/T for the expansion curve and the compression curve were calculated, it would be found that the values were about 21·4 on the expansion and about 22 on the compression, being higher, of course, on the compression curve than on the expansion curve by an amount very nearly accounted for by the change of volume due to ignition of the charge. The agreement between those two figures showed that the leakage could not have been very serious. The interesting method by which Mr. Wimperis had succeeded in calculating the temperature of the piston from observations of the change in temperature of the charge at the end of compression afforded an independent determination which the Authors found to agree well with their measurements. It might be of interest to mention that they had attempted to make a tungsten-tantalum couple from glow-lamp filaments, but had not succeeded in this; and they were much interested to learn that such couples could be made. With respect to the question of the possibility of automatically recording rapid cyclical changes of temperature, some 5 years ago they discussed this matter with the makers of the Einthoven galvanometer, with a view of using this instrument for the purpose; but at that time there were many difficulties to be overcome, and the matter was not proceeded with. Some of these difficulties had, however, been removed in more recent designs.

Correspondence.

Mr. Haeder. **Mr. H. Haeder**, of Wiesbaden, observed that the figures given in the Paper varied but little from those he had himself obtained partly by experiment and partly by estimate. The principal difference lay in the high temperatures found by the Authors in the combustion-chamber during ignition, and he had no reason to doubt the accuracy of their results.

Prof. Nägel. **Professor A. Nägel**, of Dresden, was particularly interested in the experiments described in the Paper, because he had been occupied long ago in a similar task of measuring the temperatures in the cylinder of a 300-HP. steam-engine. Recently he had included in his inquiries an 8-HP. gas-engine made by Körting Bros., of Hanover, and at the present time a 50-HP. Diesel engine was being prepared to undergo similar trials. The tests were carried out in the engine laboratory of the Royal Technical High School, Dresden, and he had published a short preliminary report on the methods of measurement and the results obtained.[1] Being well acquainted with the difficulties involved in such measurements, he could appreciate the perseverance and care in experimental work required to obtain such results as those recorded in the Paper. He had at first used, for measuring the small electromotive variations, a compensation method with an apparatus for the production of momentary contacts, similar to that described in the Paper. Two years ago he adopted the Saeten galvanometer, which was particularly suitable for the indication of temperature fluctuations, and possessed important advantages, owing to the ease of its manipulation and the completeness of the photographic curves afforded, over the compensation method, by which only isolated points could be read off and plotted. He must express a doubt as to the reliability of the temperature measurement, owing to the construction of the plugs which served for measuring the temperature of the inner walls. The cast-iron plugs shown in *Fig. 9* were apparently bored out to a diameter of about 5 millimetres, and in the surface, which had a thickness of 0·5 millimetre, a wrought-iron wire was riveted to form the thermo-electric element. He was convinced that the measured flow of temperature in the thin surface was very different

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[1] Zeitschrift des Vereines deutscher Ingenieure, 1913, p. 1074.

Prof. Nägel.

from that in the compact wall, as the latter opened to the heat flowing to it quite another channel from that afforded by the plugs. He believed he was correct in assuming that the values stated in the Paper for the mean temperature at the inner wall were too high. On account of this consideration he had adopted a different construction for the plugs used by him, a description of which was published in 1913.[1] In this connection it was appropriate to refer to researches[2] made at the Charlottenburg Technical High School by Dr. Alfred Petersen, who had obtained photographic records of the temperature flow in the combustion-chamber of a high-speed benzine engine by means of a resistance-thermometer of platinum wire 0·01 millimetre in thickness, in constructing which the experience gained at Dresden had been utilized.

Mr. Royds.

Mr. R. Royds alluded to certain large discrepancies in the Paper, that seemed to cast doubt upon the accuracy of the measurements and on the method of forming the thermo-junctions or couples in the walls. On p. 19, for instance, it was stated that temperatures at the surface of the inlet valve ranged from 12° to 18°, and at the exhaust valve varied about 12°, whilst the range at the piston was stated to be 80° at the centre and about 68° at the top. Assuming simple harmonic changes of temperature, the flow of heat into and out from the surface of the metal per cycle would be about $\frac{4\,T_1}{\sqrt{\frac{N}{2}}}$ per square foot of surface,[3] where T_1 denoted half the range and $\frac{N}{2}$ the number of cycles per minute. Assuming the average range at the piston to be 74°, according to the values given in the Paper, and that at the surface of the combustion-chamber to be about 10°, the flow of heat into the piston would be $\frac{4 \times 74}{2 \times 11} \times 0{\cdot}267 = 3{\cdot}59$ heat-units per cycle, and into the walls of the combustion-chamber $\frac{4 \times 10}{2 \times 11} = 1{\cdot}82$ heat-unit, altogether 5·41 heat-units per cycle. According to the values given on p. 11, there were only about 8 heat-units per cycle available in the gas, whereas, from the above calculations, about 5·4 units entered the walls during the high

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[1] Zeitschrift des Vereines deutscher Ingenieure, 1913, p. 1075, Figs. 3–5.

[2] Forschungsheft des Vereines deutscher Ingenieure, No. 143, "Verfahren zur Messung schnell wechselnder Temperaturen."

[3] A. L. Mellanby, "The Effects of Steam-Jacketing upon the Efficiency of a Horizontal Compound Steam-Engine." Proc. Inst. Mech. E., 1905, p. 559.

Mr. Royds. temperature period of the cycle, without taking account of any heat flowing directly to the jacket. In any case, the amount of heat entering each square foot of the walls per cycle was likely to be proportional to the fluctuation of temperature, that was, for the piston about $\frac{74}{12} = 6 \cdot 2$ times the rate at which the exhaust valve received heat. There did not appear to be any evident reason for this, and he inferred that there was something wrong with the methods used in measuring the temperature ranges. An examination of the dimensions and arrangement of the thermo-couples in *Figs. 3* and *9* showed that the metal in the neighbourhood of the couple did not even imitate the actual conditions in the metal of the valves and piston. Neglecting for the moment the presence of the comparatively thin wrought-iron wire, and assuming that the heat flow per cycle into and out from the metal through the surface was about $\frac{4\,T_0}{\sqrt{\frac{N}{2}}} = \frac{4}{11}\,T_0 = 0 \cdot 364\,T_0$, it could be shown by a similar calculation that the amount of heat passing through the metal at 0·02 inch depth in the body of the metal in the same period was of the order of $0 \cdot 24\,T_0$, where T_0 was one-half the total surface range. But with the thermo-couple, where the disk of metal was only 0·02 inch thick, nearly all the heat entering the surface had to be stored in this thin disk. Taking the rise of temperature to be proportional to the heat stored, then,

$$\frac{\text{Heat stored in 0·02 in. thick metal in wall}}{\text{Heat stored in 0·02 in. thick metal in couple}} = \frac{\text{Actual range of wall}}{\text{Range of thermo-couple}}$$

$= \frac{0 \cdot 364 - 0 \cdot 24}{0 \cdot 364} = \frac{1}{3}$ nearly. This indicated that the range of temperature at the piston, as measured, was possibly about three times too large as compared with the conditions with normal thickness of metal. The result might be modified somewhat by the presence of the thin wire forming part of the thermo-couple, but it could have been practically obviated by using a wire of much larger relative diameter than that employed by the Authors. He believed that Professors Callendar and Nicolson used the cast iron of the cylinder itself, with a comparatively thick wire soldered to the cast iron in the drilled hole. Practically the same kind of couple was used by the Authors for the inlet and exhaust valves as in the piston, except for the introduction of cast-iron plugs into, presumably, steel valves; and possibly there were considerable parasitic currents set up in the neighbourhood of contact between the plug and the valve, vitiating the results. At all events, the Authors did not appear to have made any attempt to ascertain whether any electrical potential was generated by the contact of the cast-iron plug with the metal of the valve. A similar couple, however, was inserted in cast iron at the point E in the combustion-chamber wall, but details were lacking; and, in any case, the large difference between the measured range at this point (about 9·3°) and that at the centre of the piston (about 80°) was so extraordinary as to cast doubt upon the whole of the results obtained with these couples. The Authors had constructed the thermo-couples for measuring gas-temperatures in a very ingenious manner, and seemed to have reduced temperature-lag to a minimum. Apparently, however, they had not considered the effect of radiation from the surface of the couple. It was generally accepted that the radiation from platinum varied as the absolute temperature to the fifth power. Thus at high temperatures the metal of the couple would be a fairly effective radiator to the comparatively cold walls. Probably the presence of the gases would interfere very little with the rate of loss of heat from the surface of the platinum by radiation, and Mr. Royds suggested the possibilities of gas-temperatures of as much as 100° above the values recorded, simply on account of radiation from the junction. He also suggested that *Figs. 6* and *7* would be more complete if the mean jacket temperatures were given instead of the outlet temperatures. Mr. Royds.

The Authors. The **Authors**, in reply, expressed their satisfaction that Mr. Haeder had obtained experimental results which confirmed those recorded in the Paper, and they were also much interested to learn that Professor Nägel had used similar means to those described to ascertain the temperature of the working-fluid of steam-engines and internal-combustion motors. Photographic methods of recording fluctuations of temperature were considered at the commencement of the work, but were not adopted. Recently, through the kindness of the Cambridge Scientific Instrument Company, the Authors had been afforded an opportunity of using an Einthoven galvanometer of a practically dead-beat type, and they were engaged in investigating the accuracy of the results obtained. In the surface measurements of temperature the inner diameters of the cast-iron plugs were usually under 5 millimetres, and at the centre of the piston 3 millimetres. These holes were formed by drilling with an approximately flat-ended drill, which left a fillet at the junction of the thin face with the body of the plug, so that it was hardly correct to consider

The Authors. the working face as a thin disk. The wrought-iron wires were 1 millimetre thick, and although the advantages of very thick wires were appreciated, the practical difficulties of insulating two wires throughout the whole length of a valve-spindle prevented the use of a wire of larger size. Thicker wires would probably give slightly lower values, but it was believed that the measurements were substantially free from error from that cause. The assumption of a simple sine wave fluctuation was not justified by the experimental curves; and in any given case those curves could only be represented by a series of sine and cosine terms, possibly with negative coefficients, and thereby affecting the calculations appreciably. The estimate of the possible range of fluctuation of piston temperature was materially affected by the end measurements, and in nearly all cases the range was not great; but in two trials the results approached the limits given in the Paper. Owing to the appreciable differences at the end points, 360°, without any apparent cause, the end portions of the curves were indicated by dotted lines in *Fig. 10*. Further measurements showed that there was no appreciable break in the continuity of the curve at the point in question, and this removed the discrepancy to which Mr. Royds had called attention. The valves were made of cast iron, not of steel, and parasitic currents were therefore unlikely to be present. The effect of radiation from the platinum wire would no doubt tend to reduce the temperature readings, and might be material at the highest temperatures. The calculated values of the gas-constant did not, however, support this view, and it was important to remember that the maximum temperatures at the time of explosion were determined from measurements of the pressure and volume of the working-fluid.

23 December, 1913.

BENJAMIN HALL BLYTH, M.A., Vice-President,
in the Chair.

The discussion on the Paper by Messrs. Coker and Scoble on "Cyclical Changes of Temperature in a Gas-Engine Cylinder" was continued and concluded.

13 January, 1914.

GEORGE ROBERT JEBB, Vice-President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

John Frederick Allan.
Arthur Charles Auden.
Kenneth Alfred Wolfe Barry.
Ernest Albert Seymour Bell.
Richard Bower Bristed.
Albert Brooks.
Ernest George Coker, M.A. (*Cantab.*), D.Sc. (*Edin.*).
Leonard Cooper.
Charles Augustus Copland.
Arthur Edward Cutler.
Frederick William Daniel Davis, M.Sc. (*Victoria*).
Harold Dickinson.
Frederic John Dixon.
Hugh Johnston Duffield, B.E. (*Royal*).
Francis Over Everard.
Francis Creswell Fforde.
Charles Henry Gale.
Benjamin Wrightson Head, M.A. (*Cantab.*).
Harry William Maclean Ives.
William Eyre Kenny.
John William Kitchin.
Lewis Mitchell.
William Hardcastle Neilson, B.A., B.A.I. (*Dublin*).
Reginald Godfrey Peckitt, B.A. (*Oxon.*).
Herbert James Bingham Powell.
Frederick Howell Rees.
Reginald Philip Neri Reynolds.
Edgar Gowar Ritchie.
William McGregor Ross, M.Sc. (*Victoria*), B.A., B.E. (*Royal*).
Henry Archibald Kerr Sconce.
Henry Joseph Trivess Smith.
John Percy Wakeford.
Thomas Whittow.
John Huw Williams.
William Wilson.

And had admitted as

Students.

George Robert Anderson, B.Sc. (Engineering) (*Lond.*).
Rawdon Briggs.
George Henry Harris Cook.
Dev Datt, M.A., B.Sc. (*Glasgow*).
James Dyke.
John Thomas Fitch.
John Edward FitzSimons.
Brian Edward Glover.
Laurence Brockett Holden, B.Sc. (*Manchester*).
Andrew Smith Hood, B.Sc. (*St. Andrews*).
Thomas Darling Kerr.

Students—continued.

Kundan Lal Loomba, B.A. (*Punjab*). B.Sc. (Engineering) (*Lond.*).
Eric Mallinson, B.Sc. (*Leeds*).
Moung Aye Moung, B.A. (*Cantab.*).
Stanley Frederick Philip Polhill, B.A. (*Cantab.*).
William Noel Radford, B.A. (*Cantab.*).
Wilfrid Hands Wade.
Harold Gleadow Wilkinson, B.Sc. (Engineering) (*Lond.*).

The Scrutineers reported that the following candidates had been duly elected as

Members.

Ernest Edmund Brydone-Jack.
Arthur Rodney Burch.
Ramsey Cannell.
Alfred Charles Clear.
Francis William Clements.
Benjamin Franklin Cresson, Jun.
Evelyn Brook Fox.
Joseph Humble.
Geoffrey John Phillips.
John Robert Sivess.
Talbot Francis Montague Stanley.
Graham Stewart.

Associate Members.

John Theophilus Bagram.
John Wilson Bansall.
Arthur Charles Brown, Stud. Inst. C.E.
Thomas Arthur Brown, Stud. Inst. C.E.
Clifford Chubb, B.A. (*Cantab.*).
James Clendinning, B.Sc. (Engineering) (*Lond.*), Stud. Inst. C.E.
Silston Cory-Wright, B.Sc. (Engineering) (*Lond.*), Stud. Inst. C.E.
Christopher Gabriel Eden.
Guy Whytehead English, Stud. Inst. C.E.
John Gaunt, Stud. Inst. C.E.
Allen Gidley.
Henry Herman Gordon, B.A. (*Cantab.*).
Benjamin Beaumont Haskew.
Edward Robert Kendrick, Stud. Inst. C.E.
Sidney James Kirby.
Alfred George Le Clercq.
Anthony St. George Lyster, B.A. (*Cantab.*), Stud. Inst. C.E.
Edward Mallett, B.Sc. (Engineering) (*Lond.*), Stud. Inst. C.E.
Charles Moir Mason, M.Sc. (*Victoria*), Stud. Inst. C.E.
Edwin Cyril Oakes, Stud. Inst. C.E.
Richard Edward Parsons, B.A. (*Cantab.*), Stud. Inst. C.E.
Edmund Potts.
William George Quinton.
Selby Travers Robson.
John Arthur Rodwell, Stud. Inst. C.E.
Alec Dudley Salway.
Percy George Smales, Stud. Inst. C.E.
Thomas Spence, Stud. Inst. C.E.
Richard Gilson Trower.
Edwin Frederick Warth, B.Sc. (*Birmingham*), Stud. Inst. C.E.
Edmund John Willis, Stud. Inst. C.E.

(Paper No. 4084.)

"Superheating Steam in Locomotives."

By Henry Fowler, Assoc. M. Inst. C.E.

Historical Notes.

The question of the superheating of steam to be used in steam-cylinders has engaged the attention of engineers since the inception of the use of the expansive power of steam. As early as 1705, Papin, recognizing probably the trouble due to condensation, suggested the introduction of a red-hot iron bar in the cylinder itself. The subject was also studied by Wood (1759), Hately,[1] and Mead.[2] The latter seems to have been the first to see practically the advantages possible with a superheater separate from the boiler. In 1804 A. Woolf obtained a patent[3] for superheating steam between the high- and low-pressure cylinders of a compound engine.

R. Trevithick was the first to apply the system to locomotive engines, and, in 1828, in writing to Gilbert, he mentioned that he was building a small locomotive in which he proposed to heat the steam in small iron tubes as it passed from the boiler to the cylinder. From his patent[4] it is evident that it was his intention that these tubes should be placed over the fire itself. In 1837 Jacob Perkins, in a communication to The Institution,[5] said that trouble arose with locomotives owing to the furring-up, or burning-out, of the boiler-tubes, and suggested, apparently, a boiler in which heat would be conveyed from the fire-box to the water by means of hermetically-sealed tubes containing water which would be converted into superheated steam. In the light of present knowledge, the object of the suggestion is not clear, but the following sentence[1] shows that Perkins understood thoroughly one of the physical properties of steam:—"The difference between pure and surcharged steam is, that the latter gives up its heat without condensing it, whereas the former must necessarily be condensed as it parts with its heat."

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[1] British Patent No. 895 of 1768.

[2] British Patent No. 1822 of 1791.

[3] British Patent No. 2772 of 1804.

[4] British Patent No. 6308 of 1832.

[5] Minutes of Proceedings Inst. C.E., vol. i, p. 20.

In 1839 Messrs. Hawthorn patented a smoke-box superheater, whilst between 1850 and 1870 numerous devices were brought out, including examples of practically all the types which have been experimented with in recent years.[2] Several locomotive engineers, including Mr. J. F. McConnell, of the London and North Western Railway; Mr. Moncheuil, of the Montereau and Troyes Railway; Mr. Petiet, of the Northern Railway of France; and Mr. Ingram, of the Baltimore and Ohio Railway, devised methods of superheating steam for locomotives about this time.

It seems to have been recognized early that in order to obtain the best results a fair degree of superheat was necessary, but in practice it was found that this led to trouble both with the valves and the packing. This was due largely to the lubricants and methods of lubrication used, although had piston-valves and metallic packing, both of which were known at the time, been employed, there might possibly have been further successful practical developments. As it was, however, after 1870 the use of superheated steam for locomotives was gradually discontinued, and its extensive practical use is a matter of very recent date.

About 1898 Mr. John A. F. Aspinall, M. Inst. C.E., in connection with some experiments with steam-jacketed locomotives, fitted a smoke-box superheater to one of the engines experimented upon. The arrangement was very simple, the smoke-box being extended back towards the fire-box, and having tubes fitted on each side, through which the steam passed in a tortuous path on its way between the smoke-box tube-plate and the cylinders. The experiment did not, however, lead to the system being adopted.

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[1] Minutes of Proceedings Inst. C.E., vol. i, p. 21.

[2] Mr. C. R. King, in *L'Ingegneria Ferroviaria*, in 1909, dealt with a large number of early methods of superheating steam for locomotives, but his list, long as it is, does not pretend to be exhaustive. This article is of great interest as far as the historical side of the question is concerned, and shows the large amount of attention given to the subject.

MODERN SUPERHEATERS.

Although there had been so many attempts to use superheated steam in locomotives in the earlier days of its development, and although, as stated, in the years 1850–1870 so much promise was shown, yet a want of knowledge of the effect of superheated steam on the parts of the machine, especially as regards distribution and lubrication, led to practically all attempts at its use being abandoned for about 25 years. Great as is the credit due to the early investigators, the modern development of superheating is undoubtedly due to the researches of Dr. Wilhelm Schmidt, and to the practical trials carried out by Mr. Robert Garbe, of the Prussian State Railways. In 1895 Dr. Schmidt began to apply to locomotives the knowledge he had gained in the use of superheated steam for other purposes, and in 1897 he produced his first practical design. His previous experience had indicated that the best results were to be looked for in the use of a high degree of superheat, and later experience has confirmed this.

Fig. 1, Plate 1, shows an early design employed by Dr. Schmidt, which, it will be seen, consists of a nest of pipes placed in a large central tube passing from the fire-box to the smoke-box. The view is sufficiently self-explanatory, and it is not proposed to give details of any but modern types, as, although much may be learnt from discarded models, the contemporary engineering press can be referred to for any particulars which may be required. Experience with superheaters of this type showed clearly the possibilities of the use of superheated steam in a locomotive; but, owing to the difficulties arising from the overheating of the superheater-tubes and leakage of the big tube, it was abandoned.

Attention was now given to what has always had a fascination for engineers, namely, the utilization of the space and heat in the smoke-box; and the apparatus shown in Fig. 2, Plate 1, was evolved. Dr. Schmidt realized, however, that the waste heat alone was not sufficient to give the necessary superheat, even with large surfaces, and it will be noticed that a portion of the hot gases from the fire-box was conveyed directly to the smoke-box by means of a large tube (A). Although at one time this type was adopted by the Prussian State Railways, experience showed that it had certain disadvantages: leakage was likely to occur in the large tube, and, as in other smoke-box superheaters, the liability of ashes to collect and take fire, and thus cause distortion of the tubes and joints, was a source of trouble.

The next development by Dr. Schmidt, which was first introduced as a whole about 1902, has remained in general use, with the exception of certain changes in detail, and is now by far the most generally employed for locomotive purposes. General views are given in Figs. 3 and 4, Plate 1, from which it will be seen that the smoke-tube type is reverted to, but that, instead of one large tube, a number of smaller tubes are employed. In English practice there are usually three rows of six to eight of these tubes, which are about 5 inches in external diameter, diminishing to about 4 inches at the fire-box end. In the United States, with the larger boilers employed there, the number of large (or superheater) tubes is often forty, arranged in four horizontal rows of ten each. In these fire-tubes lie the elements or the superheater tubes proper, whose shape and position can readily be seen from Fig. 4. It will be noticed that the element in which the steam is superheated consists of a pipe bent so as to form four parallel tubes, the steam having to traverse the whole length before it passes from the boiler to the cylinder. The saturated steam from the regulator enters a "header," from which it passes to the various superheater elements: after receiving its superheat it returns to a different compartment of the header-casting which is connected with the cylinder steam-chest. The construction of this header is also shown in Fig. 4. The connection between the header and the superheater elements has generally been that shown in Fig. 5, Plate 1, but recently a modification (Fig. 6) has been brought out at Derby, which is much more easily erected.

It is claimed for the arrangement of superheater here described that it gives a high degree of superheat, that it gives little trouble owing to leakage, and that repairs, when necessary, can be carried out readily and easily.

On the Great Western Railway a large number of locomotives have been fitted with the Swindon type of superheater, in which the usual large fire-tubes are employed in the boiler-barrel in two rows, one above and the other below the header. These fire-tubes contain the elements, which consist of a set of three double tubes. At the header end these are expanded into a casting of horse-shoe shape, one side of which is connected with the saturated portion of the header and the other with that containing superheated steam. The ends of the tubes near the fire-box were formerly connected by means of a steel casting, but they are now joined by a wrought-iron bend welded on to the tubes. In the small casting connecting the header there are plugs opposite each of the ends of the tubes forming the elements, so that the latter may be expanded in place, The casting itself is connected with the header by means of a single bolt, and it will be seen from Fig. 7, Plate 1, that any single element may be very easily withdrawn without disturbing any other. The degree of superheat obtained with the Swindon superheater is not so high as with the Schmidt, but very satisfactory results have been obtained with it, although its use has been practically confined to one railway.

The other superheater used at all extensively on British railways is the Robinson type, which originated on the Great Central Railway. It is illustrated in Figs. 8, Plate 1. In this superheater the tubes forming the elements bend upwards as in the Schmidt type (Fig. 3), but the ends of the tubes are connected with the header by being expanded into the bottom of the latter without an intermediate joint. Ingenious tools enable the expansion and subsequent withdrawal, if necessary, of any element to be readily effected, covers in the headers being arranged to allow of this being done.

The three types of locomotive superheaters here briefly described are those in most general use in this country. The Author is aware that there are other types of fire-tube superheaters, which, however, differ only in detail from those mentioned. He has not touched on either the smoke-box or the boiler-barrel superheater, as he believes that the former has the disadvantage of giving too low a degree of superheat for the greatest economy, and that the trouble experienced in keeping it free from ashes militates against its general use. Although many types of boiler-barrel superheater have been devised, none of them has had extended use—apparently owing to practical defects.

CONSTRUCTIONAL DETAILS.

Control of Gases from Fire-box.—It will be readily understood that, with fire-tube superheaters, the metal of which the elements are composed is kept comparatively cool when running by the constant supply of fresh saturated steam which passes through the tubes when the regulator is open. When the latter is closed the blast ceases, and under normal conditions little heated gas passes from the fire and through the tubes to the chimney. In order to maintain a sufficient current of air through the fire to keep the latter in a proper condition, it is usual to fit a steam-jet, or blower, in the smoke-box of a locomotive: this causes a stream of hot gases to pass through the tubes, and unless other precautions be taken the ends of the elements which are nearest the fire-box may be rapidly burnt away when the regulator is shut and the blower open. In order to prevent this, a damper-box is usually fixed in the smoke-box over the ends of the superheater large tubes, and this is provided with doors, or louvers, which may be opened or closed with the regulator, thus preventing the hot gases from passing around the elements when they have no steam passing through them. If these dampers be not closed at the right moment, serious trouble may quickly arise, and therefore an arrangement is usually fitted which ensures the dampers being moved automatically as the regulator is opened or shut (Fig. 9, Plate 1). A screw allows of the rods governing the automatic damper-control being varied in length, so that when necessary the damper need not be fully open.

When the smoke-box dampers are shut, the superheater elements lose their heat quickly, and they take some little time to regain it. The loss of heat occasioned by the closing of the dampers, and the tardiness of recovery, have militated largely against the employment of superheated steam for goods and stopping trains, and have led to the adoption on the Midland Railway of the damper-control gear shown in Fig. 10, Plate 2, which can be adapted for either long-distance or stopping work. The three-way cock A allows either the boiler or the header to be placed in communication with the control-valve. The position shown is for ordinary long-distance running, in which the dampers work with the regulator; steam from the header passes in through E and, opening valve B and closing C, passes through F to work the damper-operating cylinder in the usual way. For stopping trains the valve A is turned so that the steam from the header is shut off, and communication with the boiler is made through G. The damper will now always remain open, even when the regulator is closed, if D, which is worked by steam from the blower, does not come into operation. If, however, the blower be put on above a predetermined amount, steam from its supply-pipe enters through H, under the large piston D, and this in rising opens valve C and closes B, thus shutting off the steam-supply from the boiler to the damper-operating cylinder, and allowing the steam from the cylinder to escape through C to the atmosphere at M.

In the Robinson superheater dampers are dispensed with, and jets of steam are allowed to blow down the fire-tubes and thus retard the passage of the hot gases, which otherwise would pass through them and cause trouble.

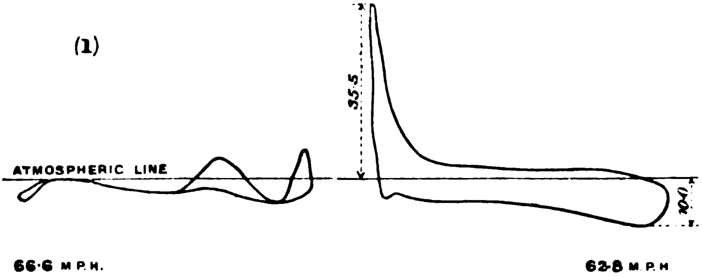
Air-Valves and By-Passes.—Engines running with any degree of superheat are usually fitted with split-ring piston-valves, and it follows that arrangements must be made to deal with excessive compression, which may arise when an engine is running with steam shut off. Originally Dr. Schmidt arranged for vacuum relief-valves and a simple by-pass connecting the two ends of the cylinders with a shut-off plug-valve in the centre, which could, when necessary, be operated from the footplate. On the Midland Railway the arrangement shown in Figs. 11, Plate 2, has been used to great advantage, the engines running without knock and coasting with great freedom. It is simple in action, the underside of the piston A being connected with the header or steam-chest. When the regulator is open, valve B is held on its seat, thus closing connection between the ends of the cylinders; when, however, the regulator is closed, valve B opens, and free communication between the two sides of the piston is maintained.

When superheated engines were first adopted on the Midland Railway, two 4-inch vacuum relief-valves with 1½-inch openings into the cylinder steam-chest were used, but by-passes were not fitted. It was soon found that serious knocking in the big and little ends of the connecting-rods took place, and diagram No. 1 in *Figs. 12*, taken from the cylinders, shows clearly the high compression which took place when coasting without steam. After the by-pass just described had been fitted, diagrams were taken again with both vacuum-relief valves and by-pass valves in operation. The result is shown in diagram 2, *Figs. 12*, and it will be seen how the excessive compression is reduced. In order to determine whether the vacuum relief-valves were necessary they were blanked off, with results which are shown in diagram 3. This is not quite as good as diagram 2, but it was found that no knocking occurred, and the practice of using a by-pass valve without vacuum relief-valves has been adopted. Opposite each diagram in *Figs. 12* is a diagram of the steam-chest pressure to the same scale. The speed of the locomotive at which the diagrams were taken is given. The fluctuations of the lower portion of diagram 2 at one end are due to the use of too weak a spring in the indicator.

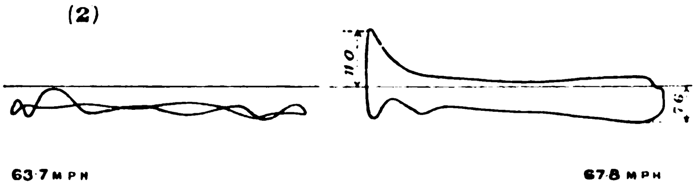
Mr. J. G. Robinson, M. Inst. C.E., has devised an automatic arrangement for the relief of pressure and suction. As will be seen from Figs. 13, Plate 2, it consists essentially of a piston A, the end of which forms the valve face B, whose seat C is somewhat smaller than the piston A. The back of A is in direct communication with the steam-chest by means of pipe D, and therefore under ordinary conditions B is kept against the seating C. When steam is shut off, or if the pressure in the cylinders becomes too high, the piston is forced back, and the cylinder is then in direct communication with the atmosphere.

Connection between Superheater-Tube and Header.—The connection between the elements and the header is necessarily a matter of importance: there are a number of these connections to be made, and it may be necessary to remove any element for inspection, etc.; so that the connection must be one which can be made easily. It must be remembered here, too, that an escape of superheated steam is not readily detected, as, if the superheat be appreciable, the steam may be dispersed before it is low enough in temperature to be

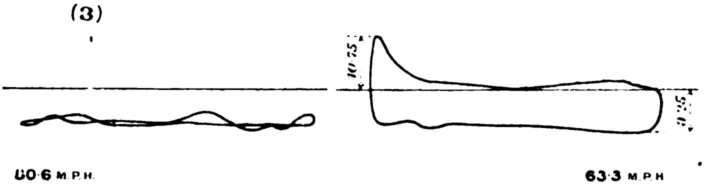
Figs. 12.



AIR-VALVES IN OPERATION & BY-PASS VALVES NOT FITTED.



BY-PASS VALVES & AIR-VALVES IN OPERATION.



BY-PASS VALVES IN OPERATION & AIR-VALVES BLANKED OFF.

condensed in the atmosphere and show as a white cloud. As previously stated, with the Robinson superheater the ends of the elements are expanded directly into the header.

In the connections shown in Figs. 5 and 6, Plate 1, a bolt or stud is used, there being a washer of some flexible or semi-flexible material between the flange or collar on the element pipe and the flat surface of the header. These washers are usually made of copper, or combinations of copper and asbestos. In the United States the usual arrangement with the Schmidt superheater is to make the end of the element into a portion of a sphere, and to allow this to form a metal-to-metal joint with a corresponding cavity in the header.

Valves and Pistons.—Piston-valves are used almost exclusively for steam-admission with superheater locomotives. This arises from the fact, which has been mentioned and will be dealt with in detail later, that there is great difficulty in lubricating efficiently moving surfaces which have heavy loads on them and to which highly superheated steam has access. Various attempts have been made to use slide-valves, but the only ones with which any success has been achieved are those which have been so nearly balanced as to render the pressure on the moving surfaces very low.

The first piston-valves employed with success by Dr. Schmidt and by Mr. R. Garbe, on the Prussian State Railways, were solid. As may be supposed, these require to be an extremely good fit, and their first cost is correspondingly high. In addition to this, they must be maintained at a very high state of efficiency, or serious leakage will take place. Tests made with a valve of this type after service[1] showed very considerable leakage when standing; but it is stated that, when running, the thin layer of oil which would exist between the faces would reduce this very largely. It is probable, however, that it is the first cost and the cost of satisfactory maintenance of these which have led to a split-ring valve being employed almost universally—at all events, outside of Germany. Fig. 14, Plate 2, shows the Schmidt type, and it will be noted that the split ring is much wider than is usually the case with ordinary piston-valves. In order to prevent undue load on the liner or excessive pressure on the outside of the ring during compression, the grooves on its outer circumference are placed in communication with the inner face by radial holes. The ring is held on the steam side by a thin plate secured by a nut at the centre. This plate, having a certain degree of flexibility, allows the ring to free itself during admission, when the pressure is the same on the two sides of the plate, but during the exhaust stroke, when leakage is likely to occur past the edges of the valve-ring, this flexible plate nips the ring, making a steam-tight joint. These rings seem to wear very satisfactorily, and one on the Midland Railway, recently examined after a service of 120,000 miles (6¼ million double strokes), showed that the ring had worn only 0·034 inch in diameter.

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[1] Proceedings of International Railway Congress, Berne, 1910, Subject V, p. 299.

The Prussian State Railways used as standard a piston-valve of very small diameter; but, probably owing to experience with saturated steam, and failure to realize the much greater fluidity brought about by superheating, many railways—especially in the United States—have employed piston-valves of very large size. Recent experiments, however, have confirmed the earlier experience mentioned.

It is necessary for satisfactory working that the piston, like the piston-valve, should float with as little friction as possible, so as to render lubrication easy. In order that this may be achieved, the piston itself is made of cast steel to save weight, whilst the rod is continued through the back cover to form a tail-rod; this latter, with the crosshead, takes all the weight of the moving piston-head and rod, leaving to the piston and gland-rings only the duty of preventing the passage of steam. The usual arrangement is to employ three piston-rings, each of the outer two having a small groove in the centre, with radial holes from the bottom of these grooves to the inside of the ring, and with their edges slightly rounded. On the Midland Railway only two rings are used, and as it was found that the grooves and holes made up with dirt, they have been omitted, the edges of the rings being well rounded. The whole of the tail-rod is enclosed, so as to do away with packing having different pressures on the two sides. It was found that when lubricated from above the rod tends to wear somewhat rapidly the bush in which it moves, but this has been prevented by applying the lubricant to the underside of the rod.

Glands and Packing.—It will be seen from the foregoing that the duty of the glands and packing is solely to prevent the escape of steam and not to support any considerable weight, as the arrangements made cause the pistons and piston-valves as far as practicable to float in their cylinders. Metallic packing, as is common on locomotives, is used, but owing to the high temperature to which it is subjected some method of cooling has to be employed to prevent it from melting. Fig. 15, Plate 2, shows a design in which the rings of white metal are placed in a box projecting from the gland and in which they are subjected to as much air-cooling as possible. Two bronze split rings, A, held together by means of springs, B, are placed inside a gland at the back of the stuffing-box near the cylinder, with a view to prevent a circulation of steam from scouring the white-metal rings. The case, C, in which the white metal packing, D, is placed, is allowed a certain amount of movement, so that it may accommodate itself to the rod. The sketch shown is for a piston-rod, but a similar arrangement is used for the valve-spindles. In another type of stuffing-box which is used extensively, the case, in which the packing and spring are enclosed, is let down into the stuffing-box and surrounded by an annular air-space for cooling purposes. If care be taken to see that the packing does not carry any weight, and if proper lubrication be given, the maintenance of these parts, once the source of so much trouble, is negligible. Cases have come to the Author's notice in which packing in stuffing-boxes of one of these types has run more than 50,000 miles, and, after being taken out for inspection, has been replaced for further use.

Relief- or Safety-Valves.—Any water which may collect in, or be carried over into, the cylinders of an ordinary engine can, if necessary, be driven out, without damage being done, through the slide-valve or piston-valve with collapsing rings. With the piston-valves fitted to superheater engines, however, it is impracticable to do this, and therefore in many cases relief- or safety-valves are fitted to the cylinder-ends of locomotives, which would open if the pressure becomes excessive owing to water. When first fitted on the Midland Railway these were 1½ inch in diameter, but were afterwards increased to 4 inches. A glance at the Robinson by-pass (Fig. 13, Plate 2) will show that it fulfils the duties required. A few (of the more recent) Midland engines have been running satisfactorily for some months without relief-valves.

Use of Special Metals.—At one time the header-castings were made almost universally of cast steel, but now cast iron is more commonly used, and with the improved designs no trouble arises. It is perhaps worthy of note that when bushes carrying the tail-rod were first put in on the Midland Railway, they were, as had been the case with saturated-steam locomotives, made of bronze composed of copper 84·58, tin 14·56, lead 0·82, phosphorus 0·01, but in a very short time it was found that the metal had broken up. Cast iron has been substituted, with satisfactory results.

Large Tubes.—It is usual to bead over strongly in the fire-box the ends of the large tubes which contain the elements, after they have been expanded in the usual way. A number of Midland

Railway engines, however, are now running in which the large tubes are not beaded over, and so far they have been satisfactory. It is also advisable to groove the tube slightly (Fig. 16, Plate 2) where it is in contact with the copper tube-plate, and when this is done there is practically no trouble with them. Whether it is due to not following this method, or to the fire-box tube-plate being of steel and not copper, or to the engines being worked harder, it is difficult to say, but in the United States considerable trouble arises with these large tubes. In some cases a copper ferrule is inserted between the tube and the plate, but this does not seem to do away with the difficulty, and electric welding of the tube into the plate has been resorted to.

Experiments made on the Pennsylvania Railroad, under Mr. J. T. Wallis's supervision,[1] show that the temperature in these large tubes is 100° to 200° F. higher than that in the ordinary boiler-tubes, probably owing to the larger volume of gases passing.

Cylinders.—The design of the cylinders does not present any great difficulty. With nearly all railways it is usual to have the admission of steam between the piston-valve heads. On the Midland Railway a few engines have been fitted in this way, but generally the admission is given on the outside of the valves and the exhaust from the centre. This simplifies the cylinder-design, valve-setting, etc., and although it necessitates having packing adapted to superheated steam on the valve-rods, this has caused no trouble whatever on the Midland system.

Size of Cylinder.—One result of the use of superheated steam, which is frequently discussed, is the possibility of using larger cylinders with the same boiler. This is a natural result, for, as is well known, superheated steam has a considerably greater volume per pound than saturated steam has at the same pressure. Advantage of this may be taken, if it is not necessary to increase the tractive effort, to employ a large cylinder and reduce the boiler-pressure, thus allowing the boiler to run a longer time between repairs. A still greater advantage, which up to the present has perhaps hardly been fully developed, is the opportunity of building locomotives which shall be more powerful at high speeds without increasing the weight by more than the superheater itself entails. This additional weight is usually about 2 tons.

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[1] Report of Tests of a class E. 6. S. Passenger Locomotive carried out on the Locomotive Testing Plant at Altoona, Pennsylvania, U.S.A., presented by Mr. C. D. Young at the Convention of the Master Mechanics' Association, May, 1913. This is probably the fullest and most complete published report of tests on a superheated locomotive.

The usual practice with engines fitted with superheaters is to allow a certain amount (about $\frac{1}{8}$ inch generally) of exhaust negative lap. It is perhaps interesting to note that on the Midland Railway this was done at first, but for certain reasons several engines were turned out without this lap. They were thought slightly sluggish, and the valves were given $\frac{1}{8}$ inch negative lap, with the result that the engines ran much more freely and the indicator-diagrams showed that the mean of the ordinates between the atmospheric line and the exhaust line was reduced about 5 per cent. There was no appreciable difference in the toe of the diagram, as will be readily understood when it is mentioned that the release which previously was 75·5 per cent. was altered to 72 per cent. at 35 per cent. cut-off.

LUBRICATION.

As previously stated, it is largely due to the advances made in lubrication, both as regards the material employed and the method of its application, that superheating in locomotives has been rendered practicable. The oil used is generally a pure mineral oil, or a blend containing up to 5 per cent. of fixed oil. It should be free from suspended matter and perfectly neutral. At ordinary temperatures the viscosity of the oil generally employed is usually so high that it will scarcely flow, and although it thins rapidly on heating, the time of efflux of 55 cubic centimetres from Redwood's viscometer should be not less than 160 seconds at 212° F. The flashing-point (closed test) should not be lower than 500° F. As far as the Author's experience goes, it is desirable that the oil should have a certain degree of volatility, so that any which becomes deposited on the walls of the cylinders or in the valves may be vaporized and pass away with the exhaust steam, instead of carbonizing and causing trouble. On the other hand, it must not be too volatile, or it will evaporate without lubricating. It will be seen that the range of the grade of oil is a comparatively narrow one, and experience shows that even oils which give good results do leave a carbon deposit on the pistons, valves, etc.; but it is found that if examinations and cleaning are done at intervals of 20,000 to 25,000 miles, no trouble is likely to occur with a suitable oil; and this can hardly be looked upon as too short a period. Although in some cases the steam in the steam-chest alone is lubricated, as with saturated-steam engines, the usual custom is to employ mechanical lubricators to supply the oil to various points. These lubricators are generally six-feed or eight-feed, and where the former are employed, the usual points lubricated are the cylinders (two connections) and the valves (four connections). On the Midland Railway an eight-feed pump is employed, which delivers to the piston-valves (four connections), piston-rod packings (two connections) and tail-rod bushes (two connections), the latter being covered with a dummy gland. 1½ to 1¾ lb. of oil is used per 100 miles run. The mechanically-operated pumps are preferably double-acting, so that the supply of oil to the various parts may be continuous, as any long interval between the feeds may cause trouble. When it is remembered that with the usual mechanical lubricator there are only a little over two strokes per mile run delivering the quantity of oil stated above, it will be seen that with a single-acting pump the pistons, etc., have a considerable travel during the time when no oil is being fed in. It is advisable to fit back-pressure valves close to the point to be lubricated, or the pipes leading from the pump will empty themselves when coasting for any distance. In considering the necessity of a regular supply of oil to the parts, it is perhaps instructive to remember that, on the basis stated above, the quantity fed in for each revolution of a locomotive having wheels 6 feet 6 inches in diameter averages 0·000135 ounce of oil at each point lubricated.

DEGREES OF SUPERHEAT.

The Author is not aware of any experiments made to show the relative economy of different degrees of superheat. With a locomotive in actual work such an investigation would be a matter of some difficulty, and it would seem that the only method would be to vary the area of the superheating tube surfaces. When an engine is being worked heavily, the draught, the coal-consumption, and the degree of superheat naturally rise, as is shown very clearly by Table XVIII, on p. 103 of the pamphlet describing Mr. C. D. Young's experiments.[1] Stationary-engine practice points to an increase in the economy with the degree of superheat, and there is no doubt this is the case, as, before proper arrangements had been made on the Midland Railway in regard to the distance run between cleaning out the tubes, the obstruction of superheater tubes caused the superheat to fall about 50° F., and drivers at once complained that their engines were not working as well as previously. These complaints ceased directly the obstructing matter was removed and the normal degree of superheat was obtained. The usual heat of the steam on superheater engines on the Midland Railway is 600° to

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[1] *Ante*, p. 86.

630° F., or 230° to 260° superheat, the bulb of the pyrometer being placed in the steam-chest, and the results given later are on this basis. Occasionally temperatures of 700° F. are reached without trouble being experienced, although it is doubtful if existing conditions would allow of this being employed continuously. In one case where a bank having a gradient of 1 in 50 and a length of 8 miles is encountered, the temperature of the steam regularly rises to 700° F., but it falls considerably in the run down the incline on the other side. It is to be hoped that figures showing the effect of different degrees of superheat will be available before long, but it would seem that they must be obtained on a properly fitted-up stationary testing-plant.

Pyrometers.—It is desirable—although not the practice in the United States, where many locomotives are now fitted with superheaters—to provide a pyrometer, so that the driver may see what degree of superheat the steam has. These instruments are of two types, vapour-tension and electric thermo-couple, but neither seems yet to have reached absolute reliability. After a little experience, however, a driver can tell whether his instrument is working correctly, and will report when it requires attention. Such an appliance is very desirable, as it shows in which position the dampers should be worked to give the requisite superheat to the steam.

MAINTENANCE.

When superheating was first suggested for locomotives, it was commonly thought that a very considerable increase in maintenance-costs would have to be faced, but experience generally has not shown this to be the case. On the Midland Railway sufficient experience has not yet been obtained to enable any actual figures upon the point to be given, but everything tends to show that the maintenance-costs per mile will not in any case exceed those of saturated-steam engines, in spite of the fact that the locomotives to which superheating has been applied have been worked much harder than when they used saturated steam. As is generally known, the whole question of locomotive-maintenance is bound up with the maintenance of the boiler, and the higher the boiler-pressure and the harder the boiler is pushed, the heavier is the cost of its repairs. With the use of superheated steam, a boiler can be worked at a lower pressure, or, if the same pressure is maintained, it can do the same work without being so hardly pushed. From the cases which have come under his notice the Author can say definitely that the boilers on superheater engines show considerably less wear than is usually the case with locomotives of the same class using saturated steam and engaged on similar work. The result is that an engine will run longer between "shoppings," and is therefore a less proportionate time out of service. In many cases it is not the boiler which first requires attention, but the wheels and axle-boxes, and if these are seen to, which is usually quite a small job, the engine may remain in service a considerably longer time before the boiler requires attention. It cannot be denied that the extra equipment on a superheater locomotive, such as elements, damper-gear, by-passes, etc., will tend to increase the cost of maintenance, but the Author believes that this will be more than compensated for by the saving in boiler-repairs.

Maintenance in the Running-shed.—Practically the only extra attention which superheater locomotives require in service is the special attention which must be given to keeping clean the large tubes which contain the elements. Under ordinary conditions the fire-tubes must be kept free from dirt and dust, and it will readily be understood that this is especially the case where obstruction is likely to be facilitated by the small tubes placed in the large ones. Originally on superheater locomotives the general practice was to employ compressed air for keeping these tubes clean, and to "blow out" from the fire-box end when the boilers were cold or nearly so. Steam could not be used under these conditions, as it would condense on the cold surfaces and tend to clog the dust. It has been found that the tubes can be kept quite clean by using steam from the boiler itself as the pressure is falling, the steam being applied by a tube-cleaner, on the end of which is a piece of ½-inch pipe flattened at the end. This may be thrust in among the elements from the smoke-box end, and will thoroughly blow out all obstructions, if the operation is carried out frequently enough. The steam may be taken from a convenient fitting by means of a flexible pipe, the cleaner being used when the boiler-pressure is between 100 lbs. and 80 lbs. per square inch. The frequency of the operation depends upon the quality of the coal used and how the engine is worked, but it is found that under ordinary conditions satisfactory results will be obtained if the tubes are cleaned after about every 300 miles of running.

TESTS OF COAL-CONSUMPTION.

The chief claim for superheater locomotives is their economy of coal. On the railway with which the Author is associated, comparisons of economy are based upon the consumption per ton-mile. The route generally selected is that between London and Leeds. The profile of the line, showing the positions of the water-troughs, is given in Figs 17, Plate 2.

In carrying out coal-tests the engines take trains in opposite directions on alternate days, i.e., while one works from London to Leeds, the other works from Leeds to London. Two up and two down trains are worked during the tests, and the results are for six or twelve trips with each engine under, as nearly as practicable, the same conditions of weather. The coal is carefully weighed on and off the tender, and an allowance is made for lighting up. The water is measured at the centre of the tender-tank by means of a gauge which enables accurate readings of the quantity of water in the tank to be taken. This gauge is calibrated to suit the tender to which it is fixed. The weight of the train is taken as the actual weight of the coaches plus 10 per cent. for passengers and luggage. The weight of the engine and tender is taken as the loaded weight of the engine plus the weight of the tender with two-thirds its maximum load of coal and water. These weights are added to the weight of the train to give the weight upon which the ton-mileage is calculated.

A number of tests under these conditions have been carried out, of which the following examples may be given. Particulars of all the engines referred to in the descriptions of these tests, and the time-tables to which the trains ran, are given in the Appendix. One test was between two engines of the "990 class," one of which (No. 998) had been rebuilt with a superheater. Table I (p. 102) gives the results, from which it will be seen that the superheater engine showed a saving of 23 per cent. of coal, and 22 per cent. of water, over the engine using saturated steam, based on the quantity used per ton-mile. After engine No. 998 had run 62,000 miles without "shopping," similar tests were carried out with it, and it was found that the coal-consumption had increased by only 1·5 per cent., and the water-consumption by 2·8 per cent., per ton-mile. It is, as the Author is aware, a matter of difficulty to compare results, which are so liable to be affected by the state of the weather, without making a very large number of tests; but he believes these latter figures will be of interest.

Similar tests were carried out under the same conditions with the superheater engine No. 998 and the three-cylinder compound locomotive No. 1,043. The tests in this case only extended over six trips for each engine, and the results, which are given in Table II, show that the consumption of coal per ton-mile with the superheater engine was 15 per cent. less than with the compound, whilst the water used was 17·5 per cent. less. The figures agree closely with what was expected from tests of a compound locomotive with one of "990 class" using saturated steam.

Two engines, namely, Nos. 484 and 489, have been rebuilt exactly alike, except that the latter has been fitted with a superheater, whilst the former uses saturated steam. These have been tested in a very similar way to those already mentioned, except that the trials have taken place between Derby and London. A diagram of the line between these points also is given in Figs. 17, Plate 2. Although a considerable portion of the route traversed is identical with the London–Leeds road, yet it is on the whole a much harder one to work. (The time-table worked to is given on p. 100). The results in Table III show that, in this case, the superheater engine gave a saving of 30 per cent. in coal, and 34 per cent. in water, over the saturated-steam engine, the basis being the ton-mile. These figures indicate a larger comparative saving than those previously cited, which is probably due to the fact that the saturated-steam engine had to be worked hard to run this trip, whilst the superheater locomotive was running well within its capacity. With two engines such as these, where the only difference is in the temperature of the steam used, a number of interesting comparisons may be made.

In order to show that, although the expansion-curve of saturated steam, partly owing to re-evaporation, does not drop as does that of superheated steam, no decrease in the mean effective pressure takes place, diagrams taken from the two similar engines have been compared. This comparison was made between a number of diagrams, which have as nearly as possible the same initial pressure, speed, and cut-off. Examples are given in Figs. 18, Plate 2, in which it will be clearly seen that expansion takes place as is expected, but that the loss which is shown here on the diagram from the superheater engine is made up by the gain in the lower exhaust and compression curve. Wherever a fair comparison could be made between two diagrams this has been done, with the result that it has been found that there is no difference in the average mean effective pressure. The exhaust lines of thirty diagrams from these similar engines were examined, and showed that whereas the average back pressure during actual exhaust with saturated steam was 7·4 lbs. per square inch, with superheated it was 3·7 lbs. When the whole of the area between the atmospheric line and the bottom of the diagram was planimetered, it was found that for the similar diagrams mentioned above the mean total back pressure for the superheater engines was 14·5 lbs. per square inch, whilst for saturated-steam engines it was 19·5 lbs. per square inch.

It has been thought that a set of diagrams from these engines would prove of interest, in order to show the characteristic points, and a number are given in Figs. 19, Plate 2, in which the cut-off is the same for each pair of saturated and superheated, whilst the speeds are shown. All the diagrams are to the same scale.

The Midland Railway Company have a number of three-cylinder compounds,[1] and a short time ago it was decided to superheat the steam supplied to the high-pressure cylinder of one of these. Although superheating in compound locomotives is practised on the Continent, some doubt was felt as to the effect of the continued high temperature in the high-pressure cylinder. So far (after 3 months' running) no disadvantages have revealed themselves, and the engine has run perfectly satisfactorily. Coal-consumption tests of engine No. 1040, using superheated steam, and of a sister engine, No. 1039, using saturated steam, have been made, and the results are given in Table IV. The tests show a saving of 25·9 per cent. in coal and 22·3 per cent. in water over the consumption with the locomotive using saturated steam. It will be seen that the coal-consumption for the superheater compound locomotive is exceptionally low.

The employment of superheated steam in goods-engines is not so general as it is in passenger-engines, either in this country or elsewhere, although in the United States a number of yard shunting-engines have been fitted, it is said, with satisfactory results. On the Midland Railway little has been done towards superheating goods-locomotives, but a couple of engines for coal-traffic have been so fitted. This traffic is usually a one-direction one, and tests have been carried out between Toton and Brent sidings, which lie 126¾ miles apart by the route taken. Toton is about 2 miles north of Trent (see Fig. 17), whilst Brent lies on the main line, about 5 miles from St. Pancras. The gradients shown on Fig. 17 are not wholly applicable, as the traffic was worked over a different road between Syston and Kettering, whilst between Wellingborough and Bedford the goods road does not lie alongside the passenger line for a considerable portion of the route, as it is carried somewhat farther round, and runs over more favourable gradients. The results of these tests are given in Table V. In each case the loaded train from Toton to Brent consisted of forty-five wagons and a brake, the average weight of a loaded wagon being 14 tons, whilst the return train was made up of eighty empty wagons and a brake. The loaded trains were weighed by being passed over a weighing-machine, the actual weight of each vehicle being taken. The results show a saving by the superheated engine of 14·3 per cent. in coal and 20·4 per cent. in water with the loaded trains, and 18 per cent. in coal and 24·8 per cent. in water for the empty train.

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[1] A comparison between the coal-consumption of these locomotives and of two other types is given in the Proceedings of the Institution of Mechanical Engineers, 1910 (vol. 2), p. 484.

There is a marked difference between the coal- and water-consumption of the loaded and empty trains, and this is partly due to the latter being worked at a somewhat higher booked speed. The undoubtedly higher resistance per ton of a light long train over a heavy short one is accountable for a very considerable portion of the variation.

FLUIDITY OF SUPERHEATED STEAM.

It is well known that superheated steam is much more fluid than saturated. Diagrams taken with two engines which were exactly similar in every respect, except that the boiler of one was fitted with a superheater, give practical confirmation of this, as will be seen from the three sets shown in Figs. 20, Plate 2. In each set the regulator-opening and cut-off were as nearly as possible identical, whilst the boiler-pressures were the same in two cases, the small difference in the third being shown. The resultant speed, which varied but little, is given, the maximum variation between the saturated-steam and superheater locomotives in the same set being 1·2 mile per hour. In the Figures the diagrams have been superimposed; the full line represents the superheater engine and the dotted the saturated-steam. Unfortunately, the steam-chest pressure is only shown for both engines on one Figure; but it will be seen how marked is the difference of fall from boiler-pressure to steam-chest pressure, the drop with saturated steam being nearly double that with superheated. The initial pressure in the cylinder in the latter case is in these, as in all other diagrams taken, much closer to the steam-chest pressure (see also Fig. 19, Plate 2). The pressure during the exhaust stroke is so small that it is difficult to show clearly what really exists, namely, that the exhaust is more complete with superheated steam. It is verified, however, by the compression-curves at the end of the diagrams.

In Fig. 19 it will readily be seen how much better the exhaust line is with the superheater diagrams than with the saturated-steam ones. It will also be apparent that the admission-line is better maintained in the former than in the latter.

The Author wishes to thank Mr. J. E. Anderson and Mr. S. Symes for the assistance they have rendered in the preparation of this Paper.

The Paper is accompanied by 20 sheets of drawings and 2 photographs, from which Plates 1 and 2 have been prepared, and by the following Appendix.

[APPENDIX.

APPENDIX.

COAL-CONSUMPTION TESTS.

General Particulars of Engines.

Engine Number.	Type.
992	4-4-0 Simple, working with saturated steam.
998	4-4-0 Simple, fitted with Schmidt superheater.
1043	4-4-0 Three-cylinder compound, working with saturated steam.
484	4-4-0 Simple, working with saturated steam.
489	4-4-0 Simple, fitted with Schmidt superheater.
1040	4-4-0 Three-cylinder compound, fitted with Schmidt superheater.
1039	4-4-0 Three-cylinder saturated compound.
3815	0-6-0 Simple working with saturated steam.
3835	0-6-0 Simple, fitted with Schmidt superheater.

Detailed Particulars of Engines.

Engine No.	992	998	1043	484	489
Boilers.					
Type	Belpaire	Belpaire	Belpaire	Belpaire	Belpaire
Grate-area . sq. ft.	28·4	28·4	28·4	21·1	21·1
Heating-surface, sq. ft.					
Firebox	151	151	151	125	125
Tubes	1,421	1,170	1,320	1,283	1,045
Superheater	..	360	..	..	313
Total . sq. ft.	1,574	1,681	1,473	1,410	1,483
Working-pressure, lbs. per sq. in.	200	200	220	175	175
Cylinders.					
Number	Two	Two	Three	Two	Two
Diameter and stroke . ins.	19 × 26	19 × 26	(1) 19 × 26 (2) 21 × 26	19½ × 26	19½ × 26
Diameter of piston-valve ins.	8¾	8⅞	HP. 10 LP. slide	8	8
Motion.					
Type	Deeley	Deeley	Stephenson	Stephenson	Stephenson
Outside lap . ins.	1⅛	1⅛	LP. ⅞ HP. $1\frac{1}{16}$	1	1
Inside negative lap . ins.	Nil	⅛	LP. ⅛ HP. $\frac{3}{16}$	⅛	⅛
Wheels.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
Coupled	6 6½	6 6½	7 0	7 0½	7 0½
Bogie	3 3½	3 3½	3 6½	3 6½	3 6½
Weight in Working Order.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.
On coupled wheels	38 10 1	39 0 0	39 2 0	34 7 0	34 9 1
Engine	58 4 3	60 5 3	59 18 0	52 18 0	53 7 3
Engine and tender	104 3 1	106 4 1	105 16 2	92 16 3	93 4 2

DETAILED PARTICULARS OF ENGINES—*continued.*

Engine No.	**1040**	**1039**	**3815**	**3835**
Boilers.				
Type	Belpaire	Belpaire	Ordinary locomotive	Belpaire
Grate-area . . . sq. ft.	28·4	28·4	21·1	21·1
Heating-surface, sq. ft.				
Firebox	151	151	125	125
Tubes	1,170	1,320	1,222	1,045
Superheater	360	..	..	313
Total . . sq. ft.	1,681	1,473	1,347	1,483
Working-pressure, lbs. per sq. in.	220	220	175	160
Cylinders.				
Number	Three	Three	Two	Two
Diameter and stroke ins.	(1) 19 × 26 (2) 21 × 26	(1) 19×26 (2) 21×26	18½ × 26	20 × 26
Diameter of piston-valve ins.	HP. 10 LP. slide	HP. 10 LP. slide	Slide valve	8
Motion.				
Type	Stephenson	Stephenson	Stephenson	Stephenson
Outside lap . . . ins.	LP. $\frac{7}{8}$ HP. $1\frac{1}{16}$	LP. $\frac{7}{8}$ HP. $1\frac{1}{16}$	1	1
Inside negative lap . ins.	LP. $\frac{1}{8}$ HP. $\frac{3}{16}$	LP. $\frac{1}{8}$ HP. $\frac{3}{16}$	0	$\frac{1}{8}$
Wheels.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
Coupled	7 0	7 0	5 3	5 3
Bogie	3 6½	3 6½	..	..
Weight in Working Order.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.
On coupled wheels	39 4 0	39 2 0	45 3 1	49 2 0
Engine	61 14 0	59 18 0	45 3 1	49 2 0
Engine and tender	107 12 2	105 16 2	86 7 1	88 2 2

COAL-CONSUMPTION TESTS.

TIME-TABLES OF ENGINE-WORKINGS.

(Only Principal Stops shown.)

Link : London-Leeds.			Link : London-Derby.	
London . .	dep. 1.30 p.m.	6.0 p.m.	Derby . .	dep. 8.55 a.m.
Bedford. .	pass 2.23 ,,	pass 6.55 ,,	Leicester .	9.32 ,, 9.44 ,,
Leicester .	3.16 ,, 3.19 ,,	pass 7.51 ,,	Kettering .	10.17 ,, 10.22 ,,
Trent . .	pass 3.42 ,,	8.13 ,, 8.15 ,,	Bedford .	11. 3 ,, 11.16 ,,
Sheffield .	4.34 ,, 5.52 ,,	9. 9 ,, 9.14 ,,	Luton . .	11.46 ,, 11.49 ,,
Leeds . .	arr. 6.57 ,,	10. 3 ,,	London .	arr. 12.32 p.m.
Leeds . .	dep. 8. 8 a.m.	10.15 a.m.	London .	dep. 2.50 p.m.
Sheffield .	8.56 ,, 11. 9 ,,	11. 4 ,, [1]	Luton . .	3.26 ,, 3.28 ,,
Masboro' .	..	dep. 1.48 p.m.	Bedford .	3.50 ,, 3.54 ,,
Trent . .	pass 11.58 ,,	pass 2.39 ,,	Leicester .	5.40 ,, 6.30 ,,
Leicester .	12.21 p.m. 12.25 ,,	pass 3. 1 ,,	Derby . .	arr. 7. 6 ,,
Kettering .	pass 12.55 ,,	pass 3.30 ,,		
Bedford. .	pass 1.17 ,,	pass 3.52 ,,		
Luton . .	pass 1.38 ,,	pass 4.13 ,,		
London . .	arr. 2.10 ,,	4.45 ,,		

NOTES.—Engines Nos. 992, 998, and 1043 were worked in the London-Leeds Link.

Engines Nos. 484 and 489 were worked in the London-Derby Link.

Engines Nos. 1039 and 1040 were worked on 1.30 p.m. ex London, and 8.8 a.m. ex Leeds.

[1] *10.15 a.m. train ex Leeds.* Engine worked "light" from Sheffield to Masboro'.

COAL-CONSUMPTION TESTS.

TIME-TABLE OF ENGINE-WORKINGS.

Engines Nos. 3815 and 3835.

(*Only Booked Stops shown.*)

Link : Toton to Brent.		Link : Brent to Toton.	
Toton	dep. 7.12 a.m.	Brent	dep. 8.10 a.m
Brentingby Junction	arr. 8.45 „ dep. 9. 3 „	Bedford. . . .	arr. 10.31 „ dep. 10.41 „
Wellingboro'. . .	arr. 11. 7 „ dep. 11.22 „	Wellingboro' . .	arr. 11.30 „ dep. 11.53 „
Brent.	arr. 3.30[1] p.m.	Melton	arr. 1.56 p.m. dep. 2. 8 „
		Toton	arr. 3.34 „

[1] Not booked.

TABLE I.—COAL-CONSUMPTION TESTS, 1911.

Date.	Train.	Weather.	Gross Weight of Train. Tons.	Ton-Miles.	Coal per Ton-Mile. Lbs.	Water per Ton-Mile. Lbs.
	Engine No. 992 (Saturated).					
24 January . .	1 30 p.m. London to Leeds	Dull, strong wind . .	302	59,843	0·107	0·93
31 January . .	1.30 ,, ,, ,,	Fine, light wind . .	299	59,250	0·108	0·94
4 February . .	1.30 ,, ,, ,,	Fine, some wind . .	301	59,526	0·113	0·97
26 January . .	6.0 ,, ,, ,,	Fine, strong wind . .	264	52,263	0·111	0·95
2 February . .	6.0 ,, ,, ,,	Some fog, light wind .	265	52,422	0·116	0·99
9 February . .	6.0 ,, ,, ,,	Fine, some wind . .	265	52,422	0·111	0·93
25 January . .	8.8 a.m. Leeds to London	Fine, strong wind . .	307	60,832	0·112	0·96
1 February . .	8.8 ,, ,, ,,	Fog, light wind . . .	293	57,946	0·106	0·92
8 February . .	8.8 ,, ,, ,,	Fine, some wind . .	324	64,148	0·100	0·89
23 January . .	10.15 ,, ,, ,,	Dull, some wind . .	279	57,880	0·108	0·94
27 January . .	10.15 ,, ,, ,,	Fine, strong wind . .	274	56,616	0·109	0·94
3 February . .	10.15 ,, ,, ,,	Fine, some wind . .	274	56,616	0·105	0·94
		Averages .	287·2	57,480	0·109	0·94
	Engine No. 998 (Superheated).					
23 January . .	1.30 p.m. London to Leeds	Dull, some wind . .	322	63,806	0·087	0·76
27 January . .	1.30 ,, ,, ,,	Dull, light wind . .	297	58,895	0·083	0·76
3 February . .	1.30 ,, ,, ,,	Fine, light wind . .	311	61,590	0·081	0·72
25 January . .	6.0 ,, ,, ,,	Dry, strong wind . .	268	53,136	0·093	0·74
30 January . .	6.0 ,, ,, ,,	Dry, strong wind . .	266	52,778	0·085	0·78
1 February . .	6.0 ,, ,, ,,	Dry, light wind . . .	266	52,778	0·089	0·76
24 January . .	8.8 a.m. Leeds to London	Dull, strong wind . .	309	61,228	0·083	0·71
28 January . .	8.8 ,, ,, ,,	Dull, light wind . .	315	62,413	0·075	0·67
4 February . .	8.8 ,, ,, ,,	Fine, light wind . .	333	65,983	0·075	0·66
26 January . .	10.15 ,, ,, ,,	Fine, strong wind . .	277	57,389	0·084	0·75
31 January . .	10.15 ,, ,, ,,	Dry, light wind . . .	278	57,516	0·081	0·73
2 February . .	10.15 ,, ,, ,,	Fine, light wind . .	279	57,713	0·080	0·72
		Averages .	293·4	58,769	0·083	0·73

TABLE II.—COAL-CONSUMPTION TESTS, 1910.

Date.	Train.	Weather.	Gross Weight of Train. Tons.	Ton-Miles.	Coal per Ton-Mile. Lbs.	Water per Ton-Mile. Lbs.
	Engine No. 998 (Superheated).					
14 December . .	1.30 p.m. London to Leeds	Wet, strong wind . .	303	59,966	0·082	0·72
12 ,, . .	6.0 ,, ,, ,, ,,	Wet, some wind . .	268	52,937	0·084	0·72
16 ,, . .	6.0 ,, ,, ,, ,,	Wet, gale	295	58,400	0·085	0·72
15 ,, . .	8.8 a.m. Leeds to London	Fine, light wind . .	311	61,545	0·072	0·66
13 ,, . .	10.15 ,, ,, ,, ,,	Wet, strong wind . .	279	57,753	0·081	0·68
17 ,, . .	10.15 ,, ,, ,, ,,	Wet, moderate wind .	276	57,267	0·075	0·70
		Averages .	288·7	57,978	0·080	0·70
	Compound Engine No. 1043 (Saturated).					
12 December . .	1.30 p.m. London to Leeds	Wet, some wind . .	303	59,922	0·091	0·84
16 ,, . .	1.30 ,, ,, ,, ,,	Wet, gale	312	61,922	0·103	0·88
14 ,, . .	6.0 ,, ,, ,, ,,	Wet, strong wind . .	294	58,241	0·086	0·79
13 ,, . .	8.8 a.m. Leeds to London	Wet, strong wind . .	311	61,545	0·102	0·95
17 ,, . .	8.8 ,, ,, ,, ,,	Wet, moderate wind .	317	62,691	0·093	0·85
15 ,, . .	10.15 ,, ,, ,, ,,	Fine, light wind . .	277	57,429	0·091	0·80
		Averages .	302·7	60,292	0·094	0·85

TABLE III.—COAL-CONSUMPTION TESTS, 1913.

Date.	Train.	Weather.	Gross Weight of Train. Tons.	Ton-Miles.	Coal per Ton-Mile. Lbs.	Water per Ton-Mile. Lbs.
	Engine No. 484 (Saturated).					
8 July . .	8.55 a.m. Derby to London and Return	Fine, strong wind	236	60,801	0·1696	1·318
9 ,, . .	8.55 ,, ,, ,, ,,	Fine, slight wind.	230	59,177	0·1627	1·333
10 ,, . .	8.55 ,, ,, ,, ,,	Stormy, moderate to strong wind.	244	62,688	0·1594	1·381
11 ,, . .	8.55 ,, ,, ,, ,,	Fine, slight wind	256	65,653	0·1618	1·313
12 ,, . .	8.55 ,, ,, ,, ,,	,, ,, ,,	253	64,991	0·1655	
		Averages .	244	62,662	0·1643	1·337
	Engine No. 489 (Superheated).					
30 June . .	8.55 a.m. Derby to London and Return	Fine, slight wind	281	72,335	0·1128	0·842
1 July . .	8.55 ,, ,, ,, ,,	,, ,, ,,	227	58,416	0·1131	0·934
2 ,, . .	8.55 ,, ,, ,, ,,	,, ,, ,,	229	58,851	0·1141	0·908
4 ,, . .	8.55 ,, ,, ,, ,,	,, ,, ,,	268	69,058	0·1183	0·873
5 ,, . .	8.55 ,, ,, ,, ,,	,, ,, ,,	260	66,774	0·1140	0·867
		Averages .	253	65,087	0·115	0·882

TABLE IV.—COAL-CONSUMPTION TESTS, 1913.

Date.	Train.	Weather.	Gross Weight of Train. Tons.	Ton-Miles.	Coal per Ton-Mile. Lbs.	Water per Ton-Mile. Lbs.
	Engine No. 1040 (Compound) Superheated.					
13 October . .	8. 8 a.m. Leeds to London	Foggy to fine	376	74,479	0·0647	0·582
14 " . .	1.30 p.m. London to Leeds	Fair, moderate wind. .	319	63,192	0·0692	0·633
15 " . .	8. 8 a.m. Leeds to London	" " " . .	342	67,679	0·0648	0·583
16 " . .	1.30 p.m. London to Leeds	"	317	62,843	0·0701	0·644
17 " . .	8. 8 a.m. Leeds to London	"	331	65,542	0·0680	0·619
18 " . .	1.30 p.m. London to Leeds	"	321	63,669	0·0684	0·655
20 " . .	1.30 p.m. London to Leeds	Fine, light wind . . .	322	63,802	0·0652	0·623
21 " . .	8. 8 a.m. Leeds to London	Fair, " "	348	69,034	0·0699	0·589
22 " . .	1.30 p.m. London to Leeds	"	318	62,974	0·0720	0·668
23 " . .	8. 8 a.m. Leeds to London	Foggy to fine, mod. wind	336	66,575	0·0676	0·598
		Averages .	333	65,979	0·0679	0·619
	Engine No. 1039 (Compound) Saturated.					
13 October . .	1.30 p.m. London to Leeds	Fair, light wind . . .	320	63,378	0·0919	0·795
14 " . .	8. 8 a.m. Leeds to London	" moderate wind. .	342	67,630	0·0895	0·820
15 " . .	1.30 p.m. London to Leeds	" " " . .	318	62,943	0·0908	0·785
16 " . .	8. 8 a.m. Leeds to London	Foggy to fine, mod. wind	310	61,415	0·0918	0·849
17 " . .	1.30 p.m. London to Leeds	Fine, moderate wind .	320	63,465	0·0880	0·779
18 " . .	8. 8 a.m. Leeds to London	Foggy to fine . . .	348	68,941	0·0847	0·767
21 " . .	1.30 p.m. London to Leeds	Fine, moderate wind .	318	63,030	0·0914	0·759
22 " . .	8. 8 a.m. Leeds to London	Fine, light wind . . .	328	64,903	0·0931	0·795
23 " . .	1.30 p.m. London to Leeds	" " " . . .	316	62,681	0·0956	0·804
24 " . .	8. 8 a.m. Leeds to London	Fair, strong wind . .	323	64,032	0·1004	0·819
		Averages .	324·3	64,242	0·0916	0·797

TABLE V.—COAL-CONSUMPTION TESTS, 1913.

Date.	Train.	Weather.	Gross Weight of Train. Tons.	Ton-Miles.	Coal per Ton-Mile. Lbs.	Water per Ton-Mile. Lbs.
	Engine No. 3,815 (Saturated).					
7 October	7.12 a.m. Toton to Brent	Wet, moderate wind	698·2	88,494	0·0869	0·797
9 ,,	,, ,, ,,	Fine, light wind	720·6	91,337	0·0672	0·641
14 ,,	,, ,, ,,	Fine, moderate wind	721·5	91,837	0·0759	0·688
16 ,,	,, ,, ,,	Foggy to fine	707·9	90,791	0·0783	0·742
20 ,,	,, ,, ,,	Fine, light wind	722·5	92,661	0·0835	0·779
22 ,,	,, ,, ,,	,, ,, ,,	698·7	89,608	0·0792	0·716
		Averages	712·1	90,788	0·0785	0·727
8 ,,	8.10 a.m. Brent to Toton	Fine, light wind	579·6	73,466	0·1150	0·925
10 ,,	,, ,, ,,	Fine, strong wind	567·1	71,885	0·1215	1·024
15 ,,	,, ,, ,,	Fine, moderate wind	567·0	71,867	0·1216	0·970
17 ,,	,, ,, ,,	Foggy to fine	578·5	73,325	0·1250	0·998
21 ,,	,, ,, ,,	Fine, light wind	567·4	71,919	0·1299	0·978
23 ,,	,, ,, ,,	,, ,, ,,	581·8	73,743	0·1213	0·975
		Averages	573·6	72,701	0·1234	0·978

TABLE V.—COAL CONSUMPTION TESTS, 1913—*continued.*

Date.	Train.	Weather.	Gross Weight of Train. Tons.	Ton-Miles.	Coal per Ton-Mile. Lbs.	Water per Ton-Mile. Lbs.
	Engine No. 3835 (Superheated).					
6 October . .	7.12 a m. Toton to Brent	Wet, strong wind . .	684·60	87,796	0·0676	0·587
8 ,, . .	,, ,, ,,	Fair, moderate wind. .	708·75	90,897	0·0695	0·627
13 ,, . .	,, ,, ,,	Foggy to fine	702·40	90,085	0·0746	0·596
15 ,, . .	,, ,, ,,	Fine, light wind . . .	723·40	92,779	0·0627	0·545
21 ,, . .	,, ,, ,,	Fair, ,, ,, . . .	706·00	89,485	0·0627	0·547
23 ,, . .	,, ,, ,,	Fine, ,, ,, . . .	679·40	86,111	0·0673	0·575
		Averages .	700·70	89,526	0·0673	0·579
7 October . .	8.10 a.m. Brent to Toton	Wet, moderate wind. .	555·40	70,402	0·1057	0·767
9 ,, . .	,, ,, ,,	Fine, light wind . . .	588·20	74,553	0·0976	0·717
14 ,, . .	,, ,, ,,	Fine, ,, ,, . . .	568·50	72,057	0·1117	0·757
16 ,, . .	,, ,, ,,	Fine	574·90	72,869	0·0930	0·721
22 ,, . .	,, ,, ,,	Fine, light wind . . .	580·20	73,547	0·0913	0·650
24 ,, . .	,, ,, ,,	Fine, ,, ,, . . .	571·50	72,438	0·1081	0·800
		Averages .	573·10	72,644	0·1012	0·735

Discussion.

The Chairman. The CHAIRMAN, in proposing a vote of thanks to the Author, remarked that it looked as if the coming of the superheater had given a new lease of life to the steam-locomotive, and it did not seem at all likely that the fine engines that were to be seen at the present time all over the country, hauling heavy trains at the rate of 55 to 60 miles per hour, would soon be displaced by any other motive power, at all events for main-line and long-distance traffic. It would be particularly interesting to hear in the discussion how far the results obtained by other users of the Schmidt superheater agreed with those of the Author, and what the experience of engineers had been who had used the Swindon, Robinson, and other types of superheaters.

The Author. The AUTHOR stated that further experiments had been made with the two engines Nos. 489 and 484, one of which was fitted with a superheater, while the other was an identical engine but without a superheater. These experiments had been made with a view to ascertain the relative values of saturated-steam and superheater engines on starting, and they had taken place on gradients. The trains experimented with were the ordinary booked trains, and accordingly there were slight variations in the loads from day to day. It was clearly shown by the results that there was very little difference until the speed attained 20 miles per hour; after that the engine using superheated steam ran considerably faster than the engine using saturated steam. In one case, on a long steady gradient, the interesting fact was disclosed that while the maximum speed that could be produced under those conditions by the saturated-steam boiler had been reached, the maximum speed on the gradient with a train of approximately the same weight using superheated steam had not been reached when the train arrived at the top of the gradient and began to run down-hill. With regard to the experiments made with the superheater compound, it might be of interest to mention that after 5 months the cast-iron slide-valves were taken out, and it was found that while they were not affected seriously, there was a certain amount of grooving. The lubrication was increased, and the cast-iron slide-valves were replaced with bronze valves; and these, although after a month's trial they showed a certain amount of roughness, were working up to a good

The Author. and satisfactory face. As to the temperature in the low-pressure cylinder of the compound engine experimented with, further tests had shown that, whereas the steam-chest of the high-pressure cylinder had a temperature of 610°, representing about 220° F. superheat, the temperature in the low-pressure steam-chest was 408°, or 100° of superheat. Those results were interesting as showing that a considerable amount of superheat had gone forward into the low-pressure cylinder. Tests had been made also to ascertain the difference (if any) between the temperatures of the header and the steam-chest, there being some diversity of practice in regard to the position of the pyrometer-bulb; and it had been found that in starting after a long stop there was a lag of about 45° F., that was to say, the temperature in the steam-chest was about 45° less than that in the header. After running quite a short time it was found that they became equal—so far as the present pyrometers on locomotives could show. After a short stop there was very little lag indeed.

Mr. Cooke. Mr. C. J. Bowen Cooke congratulated the Author on his excellent Paper. The subject of superheating had been taken up not only by those responsible for the engineering side of the locomotive question, but also by those interested in the commercial working of railways. Anything in the shape of a 25-per-cent. saving was a bait that was taken greedily by the General Manager or anyone on the commercial side. Superheating had been found to be more than a bait, and to be a benefit of real value, and personally he could more than endorse, from his own experience on the London and North Western Railway, the saving shown by the Author. The question whether an engine fitted with a superheater was to any appreciable extent less powerful than the ordinary saturated-steam engine in starting a train was one of the points which had had to be considered on the main line of the London and North Western Railway, because on leaving Euston there was a gradient of 1 in 70 for about 1¼ mile, so that the heaviest initial work was put on the locomotive before the fire had been worked up by the blast, and its starting-power was soon tested. When superheaters were first introduced some of the drivers complained that for the first part of the way they found that they were not "getting hold" of their trains quite so well as with a saturated-steam engine. He thought that was true to the extent that, in general, in starting before the engine was warmed up there was a little in favour of saturated steam; but his experience of the 1-in-70 gradient from Euston to Camden showed that it was nothing that had to be reckoned with seriously. His company

Mr. Cooke. began to install superheaters in their locomotives in June, 1910, and at the present time they had 199 engines so fitted. With the exception of one smoke-box superheater, they were all fitted with the Schmidt pattern. That showed that the policy of superheating, once decided upon, had been pushed forward rapidly. After considering very carefully the question of providing an automatic damper, he had come to the conclusion that it was not necessary, and he therefore fitted a control-lever with which the driver could work the damper when required. The suitability of such an arrangement was proved, he thought, by the long life of the superheater-tubes. The Author's damper-valve, while extremely well designed, was another part to be maintained, without, in his opinion, any compensating increase in efficiency over the hand-controlled pattern, so far as he had been able to judge from his own working. As to the wear of superheater elements, he might mention that in the case of one of his engines, after completing 224,441 miles of heavy main-line work, the superheater elements were taken out and were found to be in such a condition that they were all replaced with one exception. He had had a section made of the one tube taken out, and it was on the table for inspection. It was noticeable that there was very little sign of wear in that part of the tube where most wear and tear would be expected to take place; in fact, the wear and tear occurred chiefly at the ends of the tubes, where they came to and from the header-castings. None of his engines was fitted with a by-pass; they had simply a 3-inch diameter relief-valve of the mushroom type, fixed on the steam-chest, which was open when the steam was off; and he confessed that he had had no experience yet of the necessity of providing a connection between the ends of the cylinders. No difficulty had been experienced which had caused him to depart from the present arrangement. With reference to flat valves, his experience with them in both passenger- and goods-engines had been unsatisfactory, in spite of the fact that the valves were balanced to some extent. Although he had hoped to be able to convert some of the flat-valve engines into superheater engines, he had come to the conclusion that the game was not worth the candle, and in every case where it was decided to convert an engine it was fitted with piston-valves. It would be interesting if the Author would give some information as to the wear in the bushes and rods of the tail-rods, and also if he would say whether he had found any of the cylinders showing signs of becoming oval. It would also be useful if the Author would give some additional information respecting the average life of the packing, and an

Mr. Cooke. analysis of the metal used, because that was one of the great troubles all locomotive-engineers had to contend with, and the Author appeared to have found a way out of the difficulties. His experience of tail-rods had not convinced him that there was any great advantage to be derived from them in locomotive work, and in the design of his later types of engine he had dispensed with them altogether. They did not, in his opinion, keep the piston off the cylinder-bottom unless a great deal of attention was paid to the renewal of the bushes, with consequent increase in the cost of maintenance. It would be interesting to know if the Author had collected any information regarding the behaviour of cast-iron headers when exposed continuously to the action of superheated steam. He believed that the Author, like himself, began with steel header-castings; but personally, for some time past, he had adopted entirely, as the Author had done, cast-iron castings, of whose behaviour the Author had perhaps had longer experience. With regard to lubrication, could the Author give any information as to the use of displacement lubricators with superheater engines, and also as to the delivery of lubricant directly into the steam-pipe, as was the practice in America, compared with the mechanical lubricator described in the Paper? All the London and North Western superheater engines were fitted with mechanical lubricators; and with six feeds, one to each cylinder, and two to each steam-chest, the best results had been obtained with 1½ lb. of oil per 100 miles. He was afraid he could not agree with the Author's remarks about the pyrometer indicating the proper position of the damper, as his experience was that only two positions of the damper were necessary, namely, shut and open. No difficulty had been experienced with the simple device used on the London and North Western Railway, by which the driver was able to shut the damper when standing, and to keep it open when running. Turning to the subject of maintenance, when he began superheating at Crewe, he built two engines exactly alike in every respect, except that one was fitted with a superheater and the other was not. One was of the "George V" class—the first type of superheater engine; the other was of the "Queen Mary" class. When those engines first came in for repairs, the superheater engine having completed 95,826 miles, and the non-superheater 97,604 miles, he could not say there was very much difference so far as boiler-repairs were concerned; and in regard to the cost of boiler-maintenance, the conclusion he had come to was that there was little to choose between the two systems, except that it was possible to have a lower initial pressure in the boiler of a

Mr. Cooke. superheater engine, and consequently, as the Author justly observed, the cost of maintenance was less. Both air and steam were used on the London and North Western Railway for cleaning the large tubes, and he did not think there was much to choose between them. The Author's interesting and instructive figures in regard to the all-important question of coal-consumption were more than borne out by the results of the experiments made on the London and North Western Railway. The figures he was about to give did not refer to experiments made over a certain number of trips or days, but applied to actual work, in which the experiment—if it could be called an experiment—was spread over several months, during which the two classes of engines covered a large mileage. It was found that the saving of coal on the heaviest and fastest express passenger-trains on the main line between Euston and Crewe worked out as high as 26·7 per cent. in favour of the superheater engine. In a test taken over the heavy gradients between Preston and Carlisle with trains of the same weight, a saving of 25·77 per cent. in favour of the superheater engine was obtained. In that case, however, the results were not from the rough and tumble of actual work over a number of months, but from a series of experiments over a limited period. With regard to superheater goods-engines, of which the London and North Western had a number working heavy mineral-traffic, his experience was that the working of the engines with trains between Leeds and Crewe, where experiments were made, showed an economy of 22·6 per cent. in favour of superheating. It was also his experience that the speed had a marked effect on the coal-consumption with superheater engines, as compared with non-superheater. For instance, with a train of 357 tons running between Crewe and Euston at an average speed of 60½ miles and a maximum of 78½ miles per hour, the coal-consumption was 39·6 lbs. per mile. The same train running back on the same day at an average speed of 64·2 miles per hour, with a maximum of 75 miles per hour, consumed 45·7 lbs. per mile. With superheated as well as with saturated steam it had been found that at high speeds an increase of 2 or 3 miles per hour had a disastrous effect on the coal-consumption. Apart, however, from the economies effected by superheating, there was another side of the question, which to his mind was of even greater importance in these days of ever-increasing demands upon the British locomotive. Experience had undoubtedly proved that any saturated-steam engine, redesigned only so far as was necessary to convert it into a superheater engine, had extraordinarily different steaming qualities

[*Continued on p.* 115.

Mr. Cooke.

PARTICULARS OF THE ENGINE "RALPH BROCKLEBANK."

Cylinders (four)	16 inches diameter by 26 inches stroke.
Boiler-pressure	175 lbs. per square inch.
Diameter of driving-wheels	6 feet 9 inches.
Tractive force	23,000 lbs.
Adhesive weight	59 tons.
,, force (quarter adhesive weight)	33,040 lbs.

(1) TEST-RUN BETWEEN EUSTON AND CREWE, 2 NOV., 1913, WITH A TRAIN OF EMPTY MAIN-LINE COACHES.

Weight of train :—	
Excluding engine and tender	435 tons.
Including ,, ,, ,, ...	552 tons.
Time occupied by trip, including three slacks and one stop, equal to a total of 6¾ minutes lost	2 hours 39 minutes = 159 minutes.
Distance	158 miles.
Mean speed, including slacks and stop	59·63 miles per hour.
,, ,, excluding ,, ,, ...	62·26 ,, ,,
Mean drawbar pull over whole trip	2·4 tons.
Mean power at drawbar over whole trip.	855 HP.
Average indicated power from diagrams taken at 25 points	1,358 HP.
Average drawbar power at the 25 points where the indicator-diagrams were taken	975 HP.
$\frac{\text{Average drawbar horse-power}}{\text{Average indicated horse-power}} \times 100$	71·8 per cent.
Maximum indicated power	1,617 HP.

1 Indicator-Diagram.	2 Distance from London.	3 Gradient.	4 Speed.	5 Pull on Draw-bar.	6 Power at Drawbar.	7 Indicated Power in Cylinders.	8 Col. 7 Col. 8
No.	Miles.	1 in	M.p.h.	Tons.	HP.	HP.	Per Cent.
1	⅛	149 (down)	14	5¾	482·0	693·0	69·5
2	1	77 (up)	21	3$\frac{15}{16}$	870·0	1,155·0	75·3
3	5	(level)	51	3	914·0	1,323·0	69·1
4	10	339 (up)	57	3	1,921·0	1,353·0	75·4
5	14	339 ,,	55½	2⅞	853·0	1,388·0	68·6
6	18	393 ,,	59⅛	2¼	800·0	1,130·0	70·8
7	25	335 ,,	51	3	914·0	1,325·0	68·0
8	30	335 ,,	58	3$\frac{7}{16}$	1,150·0	1,617·0	71·1
9	53½	(level)	71	1⅞	735·0	1,088·0	73·0
10	56	326 (up)	66	2¾	1,084·0	1,532·0	70·7
11	60	330 ,,	60½	2⅞	1,039·0	1,431·0	72·6
12	72	350 ,,	66	2¾	1,084·0	1,562·0	60·4
13	76	640 ,,	63½	2¾	1,042·5	1,442·0	72·3
14	86	(level)	55	3⅜	1,109·0	1,511·0	73·3
15	91	300 (up)	66	2$\frac{11}{16}$	1,059·0	1,448·0	73·2
16	101	645 ,,	71½	2$\frac{5}{16}$	988·0	1,314·0	75·1
17	110	(level)	72	2	860·0	1,183·0	72·7
18	116	331 (up)	65	2$\frac{11}{16}$	1,043·0	1,424·0	73·2
19	123¼	408 ,,	69½	1$\frac{13}{16}$	752·5	1,085·0	69·3
20	130	351 ,,	40½	4	968·0	1,337·0	72·4
21	135	2,910 ,,	54	3¼	1,048·0	1,461·0	71·7
22	140	509 ,,	61½	2⅞	1,056·0	1,524·0	69·3
23	143	650 ,,	65	2⅞	1,116·0	1,525·0	73·1
24	145½	398 ,,	66½	2$\frac{13}{16}$	1,117·0	1,548·0	72·1
25	147¾	308 ,,	65	2⅞	1,116·0	1,554·0	71·8
Average .	..	..	..	..	975·0	1,358·1	71·7

Mr. Cooke. (2) TEST-RUN FROM CREWE TO CARLISLE ON 4 NOV., 1913, WITH THE 1.12 P.M. SCOTCH EXPRESS.

Weight of train :—	
Excluding engine and tender	360 tons.
Including ,, ,, ,, ...	477 tons.
Time occupied by trip, including slacks	142½ minutes.
Distance	141·1 miles.
Mean speed	59·4 miles per hour.
Mean drawbar pull over whole trip	1·83 ton.
Mean power at drawbar over whole trip.	663 HP.
Average indicated power from diagrams taken at 17 points	1,387 HP.
Average drawbar power at the 17 points where the indicator-diagrams were taken	920 HP.
$\frac{\text{Average drawbar horse-power}}{\text{Average indicated horse-power}} \times 100$	66·3 per cent.
Maximum indicated power	1,669 HP.

1 Indicator-Diagram.	2 Mile Post.	3 Gradient.	4 Speed.	5 Pull on Draw-bar.	6 Power at Drawbar.	7 Indicated Power in Cylinders.	8 $\frac{\text{Col. 7}}{\text{Col. 8}}$
No.		1 in	M.p.h.	Tons.	HP.	HP.	Per Cent.
1	(Starting	Diagram)	..	6¾	..	..	..
2	161⅛ (from London)	Level	57	2½	851	1,316	64·6
3	180¼	135 (up)	70½	1⅞	789	1,222	65·4
4	188	473 ,,	59	2⅝	925	1,343	68·9
5	8 (past Golborne)	104 ,,	61½	$2\frac{7}{16}$	895	1,355	66·0
6	10½	366 ,,	58	2½	866	1,383	62·6
7	3 (past Preston)	503 ,,	53½	2⅞	921	1,376	66·8
8	10	1,042 ,,	69½	1⅞	772	1,206	64·0
9	16	Level	69	1⅝	669	932	67·4
10	5 (past Lancaster)	460 (up)	69	$1\frac{7}{16}$	572	1,095	52·2
11	9	134 ,,	60½	$2\frac{13}{16}$	1,015	1,504	67·5
12	14	173 ,,	67	2⅜	950	1,407	67·5
13	20	104 ,,	52½	3⅛	980	1,494	65·6
14	24	131 ,,	47	3½	996	1,526	65·2
15	32	146 ,,	69	2⅝	1,082	1,669	64·8
16	34	75 ,,	58	3⅛	1,082	1,606	67·3
17	36	75 ,,	42½	$4\frac{5}{16}$	1,094	1,593	68·67
18	37½	75 ,,	37	5⅜	1,187	1,496	79·3
Average	..	.	..	..	920	1,387	66·3

Mr. Cooke.

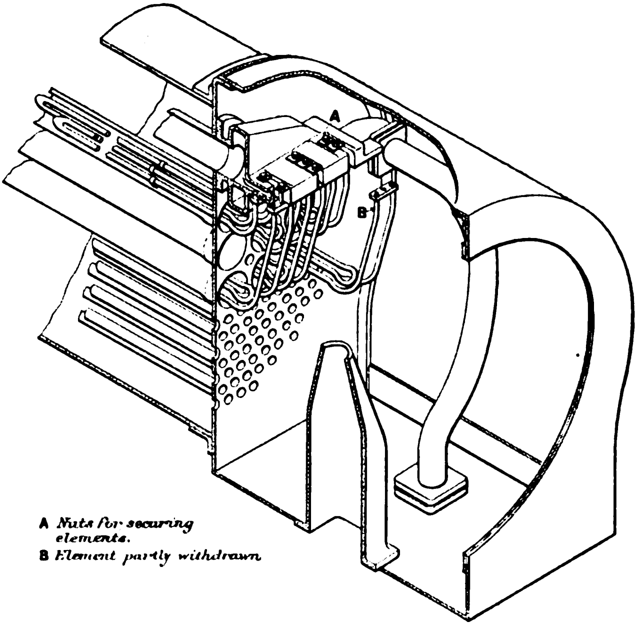
and capabilities for hauling heavy loads at high speeds. Many trains of exceptional weight and speed, which previously were a frequent source of trouble in the matter of timekeeping, were now worked day by day without the slightest difficulty by superheater engines, whilst the driver had still, as he called it, "a bit up his sleeve." He had pleasure in handing in for the information of the members particulars of some special runs made on the London and North Western Railway by the superheater engine "Ralph Brocklebank" (No. 1159), a 4-6-0 passenger locomotive of the "Claughton" class (pp. 113 and 114). He desired to congratulate the Author on the excellence of his indicator-diagrams, which in all cases showed a superb distribution of steam, and, what was most striking, practically equal distribution of the steam at the two ends of the cylinder in every case. He was afraid that on the London and North Western Railway the results were not quite as good in all cases. He wished to say, in conclusion, that the engineers, not only of the Midland and the London and North Western but of many of the other big lines, were nowadays remarkably ready to exchange views on any subject that came before them in the day's work, whether it was superheating or anything else, with the object of working together for the benefit of the engineering world at large, rather than striving independently in the dark to bring out things which, it was hoped, would redound to the personal credit of individuals within the walls of their respective establishments.

Mr. Lelean.

Mr. W. A. **Lelean** remarked that he had been struck by the modest claims of the Author, and by his acknowledgment of the work both of his predecessors and of his contemporaries. There seemed to be no doubt that the original superheater as installed by Dr. Schmidt resulted in a saving of coal and of water; but the time taken off the road by necessary repairs quite neutralized the benefits otherwise derived from that superheater. It seemed, however, to be well established now that a saving of about 20 per cent. of coal and a still larger saving of water could be obtained by the use of superheaters, without any excessive charges for maintenance; and those results were largely due to the engineers who had had the courage to adopt superheaters and had gradually perfected their details. There seemed to be no longer any reason to hesitate about fitting superheaters to locomotives. As indicating the rapid progress that had been made, it might be interesting to give some figures in connection with the locomotives sent to India for which his firm (Messrs. Rendel, Palmer and Tritton) were responsible as consulting engineers. The first superheater applied

Mr. Lelean. to a locomotive for India was fitted in 1910, and during that year seventeen engines were thus equipped. In 1911 the number fitted was the same; in 1912 twenty-two engines were so fitted; but in 1913, out of the 528 engines for which his firm were responsible as consulting engineers, and for which orders were actually placed during the 12 months, 176, or roughly 33 per cent., were fitted with superheaters. The Author pointed out three reasons against the adoption of the superheater, namely, the troubles with packing, lubrication, and maintenance respectively. Air-cooled metallic packing seemed to have settled the packing trouble; the use of special superheater oil and the introduction of the mechanical lubricator seemed to have got over the lubrication trouble; and the latest design of superheater seemed to have entirely obviated all the difficulties connected with maintenance. In the case of the smoke-tube superheater, the Running Department rather looked askance first of all at the difficulty of keeping the tubes clean; secondly, at the difficulty of removing the elements in case it was necessary to do so for repairs or examination; and, thirdly, at the blocking of the smoke-box with the damper-gear. As the Author pointed out,

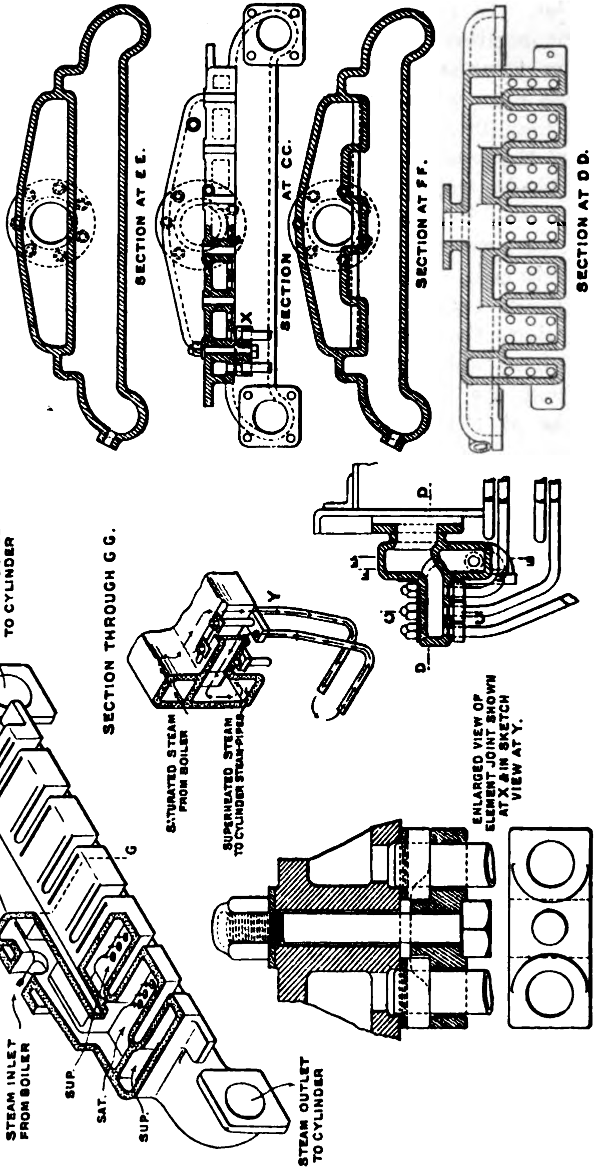
Fig. 21.



the difficulty of clearing the tubes was easily overcome by the use of a jet. In connection with the removal of the elements, he thought members might like to see the latest (Stirling) type of header, introduced by the Schmidt Superheater Company, which his firm had accepted for general use in the engines now on order for India. *Figs. 21* and *22* showed this new header, *Fig. 21* being an isometric view of the whole arrangement, showing the general construction of the header and the slots in which the bolts securing the elements slid. It would be observed that the nuts for these bolts were cap-ended, were very accessible, and, being out of the flue-gases, were not likely to become burnt, as they were in the older arrangement. This header bore certain resemblances to the header exhibited by the Author; the chief differences would be seen by reference to the isometric cross section shown at Y in *Figs. 22*, where it would be seen that the header-casting consisted of a vertical rectangular chamber at the back divided by a horizontal wall which was "staggered," as shown by the section at F F in *Fig. 22*. The top half of this back chamber was in communication with the main steam-pipe from the boiler, and therefore was always full of saturated steam while the regulator was open; the bottom half formed a continuous chamber terminating in the flanges for the usual cylinder steam-pipes. This chamber received the steam after it had passed through the elements, and therefore formed the collector for the superheated steam. At right angles to this back vertical chamber was the horizontal chamber forming a tee with the back chamber. This horizontal chamber was divided into sections by the walls of the slots shown, and the cores of this header-casting were so arranged that these sections of the horizontal part of the header communicated alternately with the top (or saturated) back vertical chamber and the bottom (or superheated) back vertical chamber. At Y in *Figs. 22* the passage of the steam through one element was traced; the rest of the arrangement would doubtless be self-explanatory. In order to get rid of the remaining difficulty mentioned, namely, the blocking of the smoke-box with the damper-gear, the Schmidt Company had put forward another arrangement which his firm had thought sufficiently satisfactory to adopt for trial on some engines. He understood the proposal originated from its having been found in certain engines, through stress of traffic-demands and shortness of time available for cleaning the tubes, that certain dampers were left off the engines without any serious ill effects resulting. The proposal which was shown in *Fig. 23* had for its object the **Mr. Lelean.**

Mr. Lelean.

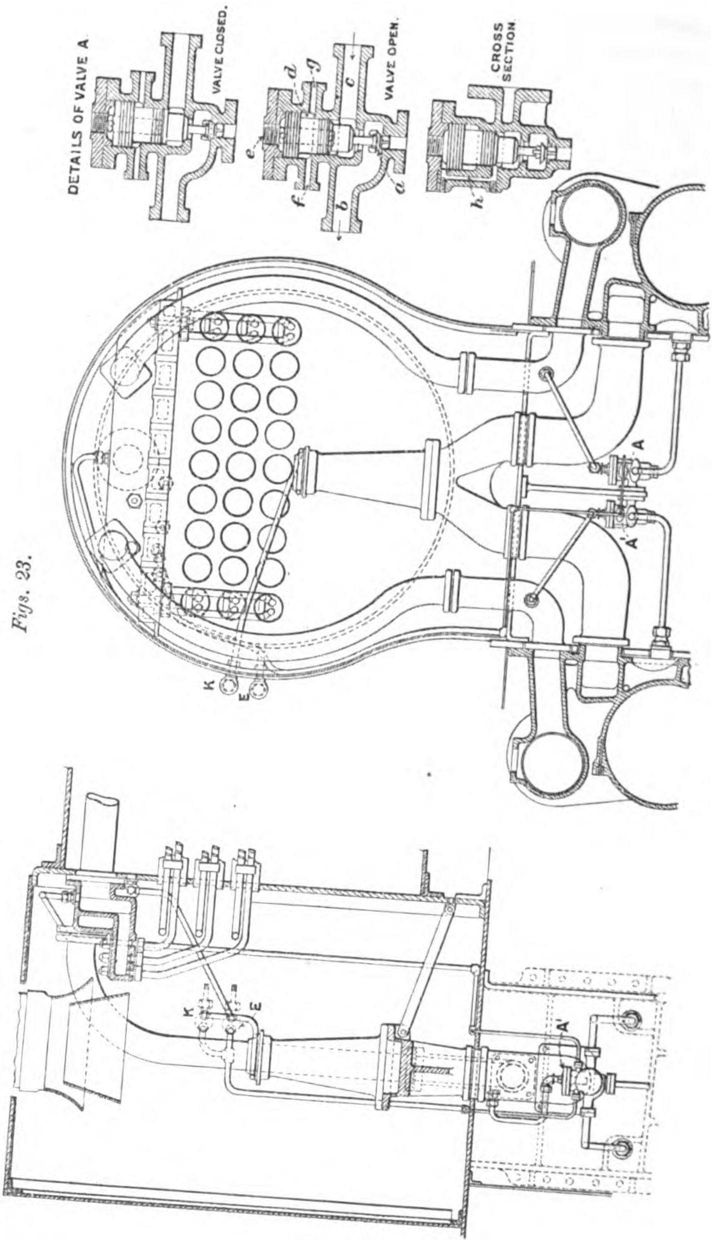
Figs. 22.


SECTION AT E E.
SECTION AT C C.
X
SECTION AT F F.
SECTION AT D D.
STEAM OUTLET TO CYLINDER
SECTION THROUGH G G.
Y
D
D
J
J
G
G
SATURATED STEAM FROM BOILER
SUPERHEATED STEAM TO CYLINDER STEAM-PIPES
ENLARGED VIEW OF ELEMENT JOINT SHOWN AT X & IN SKETCH VIEW AT Y.
STEAM INLET FROM BOILER
SUP.
SAT.
SUP.
STEAM OUTLET TO CYLINDER

omission of all dampers in the smoke-box, and it provided for the **Mr. Lelean.** passing of a small current of steam through the elements whenever the regulator was shut off and the blower was on. The danger seemed to be that the fire-box end of the superheater element might be burnt when the blower was on and no steam was passing through the elements. The first portion of the design consisted in so coupling the blower-valve K that the blower could not receive steam except from the outlet-pipe of the main cock E which led to the combined circulating, by-pass, and relief valves A and A′. It was therefore impossible to turn on the blower before creating a current through the superheater elements through the passage provided in the combined circulating, by-pass and relief valves A and A′. By inserting those valves A and A′ (shown in detail in the sections in *Figs.* 23) in the steam-pipe leading from the stop-cock E to the saturated side of the superheater header, this steam was made to operate en route the by-pass and relief valves. The steam-pipe from the cock E was connected to *f* and, before it could pass on through *g* direct to the saturated side of the header-casting and thence circulate through the elements, it had to pass through the annular chamber *d*, and so (when there was no steam-pressure on top of the piston shown) it lifted the by-pass valve (and with it the relief valve *a*), and thus established connection between the two ends of the cylinder, since passages *b* and *c* communicated by pipes with each end of the cylinder. At *e* was coupled a steam-pipe, from either the steam-chest or the cylinder steam-pipe, so that as soon as the regulator was opened the full steam-pressure acted on the larger area of the top of the by-pass valve and forced it down, thus closing the connection between the two ends of the cylinder, and also the relief valve. This circulating steam having entered at *f* passed out at *g* to the saturated side of the header, thence through the elements (keeping them from burning), and, returning to the superheated side of the header, found its way through the cylinder steam-pipes to the top of the combined circulating, by-pass, and relief valves, through *e*. It would be remarked that, in the event of the locomotive having come to rest in such a position that all the steam-ports were covered by the valves, the circulating steam, having reached the steam-chest, could get no farther and the circulation would be prevented. To meet such a contingency the passage *h* was provided. The chief feature for which they had thought it worth while to give this system a trial, apart from the abolition of the dampers in the smoke-box, proposed by the Schmidt Superheater Company, was that this circulating steam allowed the elements, the cylinders, and the

Mr. Lelean.

Figs. 23.


DETAILS OF VALVE A
VALVE CLOSED.
VALVE OPEN.
CROSS SECTION.
a
b
c
d
e
f
g
h
A
A'
K
E

steam-pipes to be kept hot: material benefit when starting was therefore expected, from the avoidance of initial condensation. In conclusion, there was one point he thought might be of interest in connection with the lubrication of the tail-rods; it was reported to his firm that benefit had been found from introducing oil from the forced-feed lubricator on the under side of the tail-rod, so forcing the film below the rod and floating it, instead of introducing the oil from above. Mr. Lelean.

Mr. Clarkson. Mr. T. CLARKSON observed that the Author's very interesting Paper revived a number of reminiscences of early experiments in the use of superheated steam, some of the experience then obtained being not altogether pleasant. He remembered one occasion on which a copper steam-pipe was used between the superheater and the engine. It was very soon discovered that copper was a most unsuitable metal to use in that situation; it would not stand the high temperature, soon becoming crystalline and losing its tenacity. Wrought hydraulic pipe was used in the same situation, and that also came to grief. Lap-welded steel very soon gave out, and the only material that was really of any use was solid-drawn steel tube. His own experience was not on railways but with road-locomotives and steam-cars, in which a considerably higher degree of superheat was used than in the engines to which the Author referred. He had used superheat up to 1,000° F., but he had found no advantage in that temperature over one of 750° to 800°, which was what he generally used. The Author appeared to be using a temperature about the melting-point of lead, say, 620°. At one time he had thought that the melting-point of lead or of some alloy might be a very convenient method of indicating or controlling the degree of superheat, which had been one of the great difficulties experienced. He had endeavoured to overcome that difficulty by automatic methods, such as the employment of a thermostat, and obtained a fair degree of success. The difficulty was to make a reliable thermostat which would work at the temperatures in question. Copper and bronze were not reliable, and ultimately a mild-steel tube was used, working in conjunction with a rod of steel containing about 25 per cent. of nickel, which had practically no coefficient of expansion. Mild-steel tube was also used, in combination with a porcelain plug, contained in the tube, which had practically no expansion. In one case during the testing of a steam-car, a boy who was riding at the rear of the car noticed, as the day was getting over and dusk was coming on, that the steam-pipe occasionally became red. That was the indication adopted. When the boy said the steam-pipe was

Mr. Clarkson. red the driver turned down the fuel; when it became black he turned it on again; and that plan worked very well. It gave an excellent indication of the temperature, which he judged to be somewhere in the neighbourhood of 800°, or incipient redness, which was a very suitable temperature for the conditions under which the car was then being run. Superheat gave life to an engine; sluggishness and want of life were indications of want of superheat. It was possible to do things with superheated steam that could not be done without its aid. In making steam the chief item of expenditure was the latent heat which had to be put into the water to convert it into steam without any sensible rise in temperature. The main advantage of superheating was that it reduced that item of expenditure in proportion to the volume of steam available for filling the cylinders. Not only so, but superheated steam was more in the nature of a perfect gas, and could do work without changing its physical state by condensation. That was a great advantage in the engine-cylinder. Another advantage, which was touched upon in the Paper, was the greater liquidity or mobility of superheated steam, enabling it to pass in and out very rapidly. Incidentally that gave the further advantage that smaller ports and passages could be used, and therefore smaller valves, which meant smaller masses to reciprocate and lower pressures. With the small powers used on the road the best results had been obtained from the slide-valve, made of bronze. Piston-valves and mushroom-valves had been tried, and also chilled cast iron with ground face, which worked very well provided the lubrication never failed; if it failed the port-face was destroyed very rapidly. With regard to packing, white-metal packing had to be discarded very soon, because it melted, and for a long time braided bronze wire had been used, which answered very well indeed. A washer of composite material was placed between each two rings of packing; the joints were broken, and the packing lasted well, no trouble being experienced from that cause. With regard to lubrication, the tendency had been to do without it. The slide-valves were taken out and given a dressing of graphite, the face being rubbed on a board with graphite. Success had not been attained in feeding graphite in with either oil or water, but if the valve was occasionally dressed with graphite, and a little oil of very high quality was used—pure mineral hydrocarbon oil with 2 per cent. of neat's-foot oil incorporated—it answered very well.

Mr. Hill. Mr. A. J. Hill, referring to the statement (p. 85) that piston-valves were used almost exclusively in superheater locomotives, remarked that his own experience did not bear out Mr. Bowen

Mr. Hill. Cooke's view, that it was not worth while fitting superheaters to existing locomotives without at the same time putting in new cylinders with piston-valves, etc. He had come to quite the opposite conclusion. Two or three years ago, when the Great Eastern Railway first started superheating, Mr. S. D. Holden built two of the standard 4-4-0 express engines with Schmidt superheaters, using the ordinary cylinders and slide-valves, special oil-holes being drilled in the port-bars to lubricate the ordinary phosphor-bronze valves upon the face. He had had the work of those engines watched very carefully and the wear of the slide-valves taken into consideration. He did not suggest, of course, that he would build new engines with slide-valves, but these engines were of the standard pattern, and the experience with them had been decidedly satisfactory. The valves wore out faster than was the case with similar engines using saturated steam, but they gave no trouble; they were easily replaced, and the extra expense due to the slide-valves was small in comparison with the saving of coal which had been obtained (about 20 per cent.). Greater economy might have been obtained by putting in piston-valves, but he did not think the expense of the extra work in cylinders, motions, etc., would have been repaid. He was so far satisfied with the results that he was equipping about twenty more slide-valve engines with superheaters, and he considered it was well worth while to do that, rather than go to the expense of piston-valve cylinders, etc. With regard to large tubes, or smoke-tubes, he was sorry to say that his experience was not as favourable as the Author's; he had experienced considerable trouble with them. He wished he could adopt the Author's plan of doing away with the beading and fixing the tubes in the simple way described in the Paper. He had commenced the practice of screwing the tubes into the tube-plate—which originated, he believed, with Mr. Churchward—and the trouble had been overcome; but up to the time of screwing in the tube great trouble was experienced in getting the tube tight. As to the degree of superheat, he did not know whether, in that connection, the Author was thinking necessarily of the same system of superheater; but he wished to say that at the same time as the two engines to which he had referred were turned out, two precisely similar engines of the same batch were fitted with the Swindon superheater. Speaking subject to correction by Mr. Churchward, that system did not give so high a degree of superheat, the temperature attained in the Schmidt apparatus being 650° F. and in the Swindon superheater a little over 500° F. He said "subject to correction" because in the case of the engines fitted

Mr. Hill. with Schmidt superheaters the heat had been tested with pyrometers, but not in the case of the Swindon superheaters. He was therefore not quite certain as to the superheat obtained with the Swindon superheater, but he thought it was about 500°. Two slide-valve engines fitted with the Schmidt superheater and two slide-valve engines fitted with the Swindon superheater had been compared on similar work, and he had found that in the former there was a saving in coal-consumption of 20 per cent. and in the latter of about 14 per cent. As to the employment of superheated steam in goods-engines, ten large goods-engines on the Great Eastern Railway had been fitted with the Schmidt superheater, and had been employed on work which, unfortunately, was least suited to superheater work —that was to say, trains subject to considerable delays; and, as the engines were not fitted with any special appliances—either snifting-valves or means of passing live steam through the elements—they were considerably handicapped, and the average saving of coal was only about 10 per cent. On particular trips it was, of course, a good deal more; but even 10 per cent. was a considerable saving in engines employed on work least suited to the use of superheaters. These engines had been compared with precisely similar engines using saturated steam. He had recently turned out two engines fitted with the Robinson superheater, but he had not yet had an opportunity of compiling the results. The slide-valves to which he had referred were not balanced; they were ordinary D valves.

Mr. Stenning. Mr. H. A. STENNING, who expressed Dr. Schmidt's regret that his health did not enable him to be present, said there were one or two interesting points in the Paper to which he wished to refer. The Author's statement that, up to a speed of 20 miles per hour, the saturated and superheater engines were about equal in acceleration had been confirmed by Mr. Cooke, and Mr. Stenning had hoped that Mr. Hill would refer to the equally heavy gradient up to Bethnal Green. It was easy to understand that equality. It took a little time to get up the temperature with superheater engines, and until they were warmed up the benefit of the superheat was not obtained. The result of that fact being brought to his notice had been that the combined by-pass and steam-circulating valve shown in Figs. 23 was devised. It was a modification of a design used by Mr. Raven with a view to pass steam through the elements and cylinders, keeping the cylinders warm and the elements cool, so that the losses due to the condensation of steam coming into cold cylinders were avoided. Mr. Raven, who had fitted many engines on the North Eastern Railway with similar apparatus, had informed him that he had obtained

Mr. Stenning.

very beneficial results from it, including a high temperature at the very start. With reference to superheating in compound engines, the Author had taken an ordinary saturated-steam compound engine and had applied a superheater to it. Mr. Stenning had worked out roughly the ratio of the cylinder-volumes of the high- and low-pressure cylinders, and had found that it differed considerably from what was usually aimed at in superheater practice. The Author's ratio was 1 to 2·44; whereas data he had of continental compound superheater engines gave a ratio of 1 to 2·15 or 2·3. There was a great deal more of continental experience available of compound working than there was of British, and abroad they seemed to increase the diameter of the high-pressure cylinder. The Author spoke of getting 100° of superheat in the low-pressure cylinders, the temperature being 610° for the high-pressure and 408° for the low-pressure. That would mean a steam-chest pressure in the low-pressure cylinders of about 140 lbs. per square inch. He thought it was lower than that, and that the Author really obtained more superheat than 100°; but he would be glad to know. At all events this showed clearly the economy of superheating in a compound engine. A certain amount of superheat was obtained in the low-pressure cylinder, and, therefore, under certain working-conditions, where a compound engine was economical, the superheater augmented that economy. Mr. Cooke had given a higher figure for coal-consumption than the Author, and Mr. Stenning thought that was entirely due to the fact that the loads to which Mr. Cooke had referred were considerably heavier than those which the Author had taken. One point that had not been mentioned was that the performance of an engine could be improved by superheating. The more a superheater engine was flogged the more economical it became. The poorest engine ever worked became at once a practical machine when a superheater was fitted to it; it ceased to be a great coal-consumer, and it did its work within reasonable limits. With regard to metallic packing, he did not know what mixture the Author was using, but his own experience was that a mixture of 80 per cent. lead and 20 per cent. antimony was the best. If that mixture was carefully run into a pig, and the pig run into moulds, care being taken that the metals were not fused by too high a temperature when mixing, no trouble should be experienced with the packing. He certainly thought that air-cooled metallic packing was an improvement, but if springs were used to keep the packings in position they should be kept as far away as possible from the high temperatures. It would be interesting to see the results Mr. Cooke had obtained without tail-

Mr. Stenning. rods. It had been usual for engines with 18-inch cylinders to have tail-rods, but it was well known that the tail-rod bushes wore badly. He had recently suggested that if the tail-rods were lubricated underneath by a mechanical lubricator the wear would be less, and that would be found to be a better method of lubrication than the usual plan of lubricating on top of the tail-rod. Mr. Clarkson's remarks had shown clearly that he obtained a much higher degree of superheat than locomotive-engineers attempted. There was a good deal of information available in regard to continental practice with steam-locomotives, steam-ploughs, and lorries, and he was able to confirm entirely the figures Mr. Clarkson had given. Any one who had ever ridden on a White or a Stanley superheated-steam car would have noticed in going uphill that the higher the degree of superheat the more lively the car was. It was much easier to get up a hill with 1,200° of superheat than with 1,000°. In the same way a superheater locomotive was much more lively than an ordinary saturated-steam locomotive. In view of that experience he believed that the use of much higher degrees of superheat than at present would become usual. Experiments on this point were being made, and if the results were as he expected, the form of the locomotive-boiler might be changed—and that sooner than most people thought. He thought the action of superheated steam on copper was a physical action, and he attributed failure of that metal to the velocity of superheated steam, which caused it to have a cutting action on copper. He had seen some main steam-pipes of copper which, after a few weeks' service, had furrows cut in them like the ridges of a ploughed field. He wished Mr. Hill and the Author every success in their further experiments with slide-valves. Mr. Clarkson had apparently overcome all his troubles with these valves at high temperatures. Mr. George Hughes was probably the first engineer in England to adopt slide-valves with superheated steam, but they were balanced slide-valves. Mr. E. E. Lucy, of the New South Wales Government Railways, had a large number of engines now in service with balanced slide-valves, of which he heard very good reports. They were partially balanced, not so fully balanced as Mr. Hughes's; but they were not the ordinary slide-valve adopted by Mr. Hill. The slide-valve question seemed to be an open one, on which further experiments ought to be made. With regard to lubrication, in the United States all high-degree superheater engines used nothing but displacement lubricators; he believed various English locomotive-superintendents used them, and he saw no reason why they should not be successful. The Prussian State

Railways had adopted them in recent years, and they had also been fitted on one or two engines in South America. Many people argued that if a sight-feed or displacement lubricator was adopted which introduced the oil into the cylinder the superheat was lowered. He had found it difficult to get anybody to carry out experiments to test that point, but eventually on a South American railway two similar engines were fitted, one with a displacement lubricator on the right-hand side, and one with a mechanical lubricator on the left-hand side, and the steam-chest temperatures were registered. Speaking generally, it was found there was an average fall of temperature of about 20° F. with the displacement lubricator. Not being at all convinced by those experiments, he applied to South Africa, where the whole of the Union railway-engines, with the exception of the first ten, were fitted with displacement lubricators, although he believed the first ten had now been fitted with them; and he had received a report saying that, although no exact experiments had been made, no reduction of temperature or of the working efficiency of the engines had been found through the use of displacement lubricators. It was not easy to compare experiments or experience of that kind, because the conditions might be altogether different. In South America possibly great care had been taken with the pyrometer measurements, while from South Africa only a general statement of experience had been obtained. At the same time he thought, in view of the American and the Prussian practice, that no fear need be felt in using a displacement lubricator with superheated steam. If a displacement lubricator were fitted, the oil should be sprayed into the steam-chest and not into the steam-pipe. The only data he possessed where the temperature was above 700° came from South America. He could not give the exact figure because he was told when the needle of the pyrometer got up to that point the observer ran away, and the report stated that the temperature did not remain at that point long enough to see if it increased the efficiency of the engine. He thought, however, that the extra 60°, say from 610° F. to 670° F., if it could be obtained, was worth getting. He had hoped the Author would deal with the question of the diameter of the blast-pipe top, but apparently he had not thought it worth troubling about. At the present moment that point was giving him considerable trouble. He was collecting information from all parts of the world with the object of ascertaining the diameter of the blast-pipe top, the height of the chimney, the length of the petticoat, and the height of the blast-pipe, in relation to various degrees of superheat and various Mr. Stenning.

Mr Stenning. consumptions of coal. There seemed to be no rule by which the correct diameter could be determined. There was no doubt the diameter had a distinct influence on the superheat, because in some engines sent from England to India and other places the diameter of the blast-pipe top had had to be altered in order to get a good superheat temperature. He was now endeavouring to establish some formula by which the diameter could be ascertained. That point, however, might not be of great importance at home, where the conditions were very different from those in other parts of the world.

Mr. Aspinall. Mr. JOHN A. F. ASPINALL wished to call the Author's attention to a slight error on p. 78, where he referred to the superheater which Mr. Aspinall fitted on a Lancashire and Yorkshire engine in 1898. The Author was evidently under the impression that only one engine was fitted, but as a matter of fact six engines were fitted, four of which were still running. That superheater did not give anything like sufficient superheat, or anything like the superheat which could be obtained with modern appliances, although it did a certain amount of good work, the engines on which it was fitted running somewhat more freely than their fellows. But once his company were satisfied that the superheater produced by Dr. Schmidt had arrived at such a stage that it could be safely used, they adopted it at once, with considerable advantages. Since that time many changes and improvements had been made. His company had now several forms of superheaters of British design in use. The form of superheater used on the Lancashire and Yorkshire Railway,[1] designed by Mr. George Hughes, was a thoroughly workmanlike and good appliance. Speaking of superheating from a commercial point of view, the Lancashire and Yorkshire Railway Company had obtained all they expected from its use. Considerable saving in coal had been effected, which was a very satisfactory feature at the present time, when coal was becoming so much more expensive than it used to be. That was shown by the fact that the locomotive-coal which his company used to purchase from one pit in 1886 at 5*s*. 6*d*. per ton at the pit, cost at the present time 11*s*. 6*d*. per ton. Of course, in taking out the total cost the carriage had to be added to the cost of the article itself. The superheater had fortunately come into use at a time when not only was coal much more expensive than it used to be, but railway-companies were using much larger engines, pulling much heavier loads. It was very common on some of the railways hauling coal- or goods-trains

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[1] *Post*, p. 181 *et seq*.

Mr. Aspinall.

to take well over 1,000 tons behind the tender. The consumption per train-mile was therefore larger, and it became more necessary to economize in every possible way, in order to reduce the coal-bill. He did not know of any invention produced within the last 40 years which had had such a marked effect upon the economy of the locomotive. He thought it was by far the greatest advance that had been made in that period, and the experience of it on the railway with which he was connected had been of a very satisfactory character.

Mr. Churchward.

Mr. G. J. **Churchward** agreed with Mr. Aspinall that superheating had done more for the economy of the locomotive than anything that engineers had taken in hand. He noticed that the Author, in the historical portion of the Paper, said that the Swindon form of superheater was in effect giving a low degree of superheat. He feared the Author must be labouring under some misapprehension. The position in which the pyrometer was placed—whether in the superheater-header or in the steam-chest—made a very considerable difference; and up to the present he had not succeeded in obtaining a pyrometer which in a succession of trips gave the same results. It had to be calibrated before and after every experiment made. From observations he had had opportunities of making of the pistons, the valves, and the valve-chests of locomotives of other railways, it appeared to him that the superheat which was being used on the Great Western, if one could judge from appearances, was rather higher than that commonly employed in England. He knew that statement would be contested by some of his friends who were present, but he would be very pleased at any time, if they did not agree with the conclusions at which he had arrived, to show them the evidences of superheat in the Great Western cylinders and valves, as compared with those which they found in their own locomotives. With regard to the use of metallic packing with superheaters, many years ago, when he commenced to fit superheaters, he had to abandon entirely the use of metallic packing, which melted out after a few miles' run. He had found it impossible to use copper steam-pipes for the same reason, and had had to adopt steel. He had noticed that the American Master Mechanics Association had had the same experience, and had called attention to the undesirable effect of superheat on cast iron. He mentioned that point simply to emphasize the fact that up to the present the use of a pyrometer had not been an altogether reliable means of ascertaining how hot a particular thing in a locomotive was. On that account he hesitated to give any temperatures of his own; but the pyrometer-readings on the Great Western engines, taken

Mr. Churchward. in the steam-chest, reached 550° to 580° F. with 225 lbs. pressure per square inch. He saw no difficulty in obtaining any temperature required. Even in the Swindon superheater, any definite proportion of the fire-box gases could be passed through the superheater and the fire-box tubes below, respectively, by altering the angle of the damper. In fact, the whole of the gases could be put through the superheater, in which case he presumed everything would be melted out. At all events no difficulty had been experienced in getting the figure he had mentioned. He must protest against the form of blast-pipe shown in the Author's illustration of the Swindon superheater: nothing like it was ever used on the Great Western Railway. He thought that if engineers were not careful much misconception would arise in regard to the use of superheat. It was incorrect to say that the maximum superheat should be aimed at. Any given engine required a certain degree of superheat for maximum economy. On the Great Western no notice was taken of slide-valves—they were all balanced, of course—or of piston-valves; the boilers were fitted quite independently of the valves; but it had been noticed that engines of modern design with a very small cylinder-clearance did not show the same degree of economy as was shown by older engines in which the cylinder design was, in the first place, not so good, and, in the next place, gave much more clearance. It was quite reasonable that that should be so, because a great deal of the advantage obtained from superheating was due to reduction of the cylinder-losses, which were much in proportion to the cylinder-clearance. In a modern and, he thought he might say, first-class locomotive, only about 10 or 12 per cent. improvement was obtained on the Great Western Railway, but in older locomotives in which the cylinder-design was not so good, in which the ports were longer and more tortuous, and in which the cylinder-clearance was 1½ to 2 per cent. greater, 20 per cent. economy was easily obtained. There was no difference in the boilers—as a matter of fact the boilers were changed over from one engine to another—and there was no difference in the superheat; so that there was something to be considered beyond the mere degree of superheat which was obtained. He agreed with the Author as to the difference between goods-engines and engines employed on stopping trains and those employed on through running. It was clear that, with the normal pattern of superheater, less economy was obtained with goods-trains and stopping trains than with through trains. He thought that if the Author could so adjust the arrangement which he described as to give the same amount of superheat for the slow

Mr. Churchward.

trains he would certainly get a considerable advantage. With the coasting difficulty, which, in Mr. Churchward's view, was very serious in the superheater locomotive, he had dealt in the following way. An auxiliary steam-pipe, which was under the control of the regulator, came into action before the main valve was opened, took the oil from the lubricator on the foot-plate, and then distributed it to the steam-chests. In coasting that auxiliary steam-pipe was in action, and it was taking oil to the steam-chests at the same time. In that way the piston and the valves were floating in a lubricated vapour instead of running dry, as they would do if some such arrangement were not made. It had been found in the Great Western experiments that with the straight lubricator, if it might be so called, which delivered the drops of oil direct to the tops of the cylinders and the tops of the steam-chests, the oil was not distributed over the surface so evenly and so well as it was when it was distributed by the aid of the auxiliary steam-pipe. Clearly it could not be so well distributed when the engine was coasting and using no steam. He was very interested to see that the Author had been successful in using cast-iron bushes for tail-rods. He would be very glad to have further particulars on that point, because, although he did not use tail-rods, he would like to see how the Author got cast-iron bushes to give good service in such a connection. Was it quite certain that the tail-rods were carrying the pistons and the valves respectively? He once made an experiment with some tail-rods, and although they looked all right it was quite obvious on a detailed examination that the pistons were carrying the rods. As a consequence of that, he was happy to be able to say that there was not a tail-rod on the Great Western Railway. It was true the diameter of the pistons did not exceed 18½ inches in any case. He was rather surprised at the weight of 2 tons for the superheater, because on the Great Western it did not come to more than 17 cwt. As a matter of fact, there was some saving of weight in the distribution of the tubes in the boilers, because a superheater engine was only about 9 or 10 cwt. heavier than a saturated-steam engine of the same class. He cordially agreed with the Author in the observations he made as to pyrometers, and also in his observations upon the improvement in the behaviour of the boilers, and he was not sure that that improvement was not the second best advantage obtained from superheating. He found, as the Midland Railway had found, that the superheater boilers did not give so much trouble with their tube-plates, or tubes, or fire-boxes. Even if no saving of coal were effected, he was not at all sure that he would not fit super-

Mr. Churchward. heaters for the purpose of obtaining the advantage in connection with the behaviour of the boilers. In conclusion, he would say, to paraphrase an Americanism, "It is the coal-pile that talks." The Great Western had been fitting superheaters for some years, but they had not done much in the way of making experiments. They began, however, years ago, when they started with superheating, to keep a record of the coal issued to the same classes of superheater and saturated-steam engines respectively, and they had continued that practice to date. Taking the 12 months' working in 1913, he found that the number of superheater engines actually running during the year was 625, and, compared with their sister engines of the same class, they had saved 60,000 tons of coal. There was another trite saying that, "The horse may starve while the grass is growing." If engineers waited until innumerable experiments had been made to define the last degree of superheat that could be obtained, they might miss a good deal of coal in the interval. The Great Western had altogether 750 engines fitted with superheaters, as well as a number of boilers ready to change as the engines passed through the shops. He quite agreed with what Mr. Hill had said in regard to slide-valves. The Great Western Railway had about 200 engines running with slide-valves, but they were all balanced, which made a difference. They gave more trouble, in that they wore out more quickly, but, as Mr. Hill said, they were worth it.

Mr. Rosenthal Mr. J. H. Rosenthal remarked that the Paper was not only valuable to the locomotive-engineer, but was also of great interest to those accustomed to deal with superheating in other branches of engineering, and of particular interest to him, as one of the first persons to design a small-tube superheater. He did not know whether any attempt had been made to work the Midland superheater without a damper in the fire-box. If so, it would be interesting to know the result; because, looking at the design as a design, his opinion was that the superheater could not possibly last any reasonable time without considerable repairs, if it were not for the very ingenious smoke-box damper that seemed to be part of the design, but was not prominently referred to in the Paper. Another point which had had to be borne in mind since the resuscitation of superheating—that was, since the time when small seamless steel tubes were introduced—was the fact that such tubes, of ductile and pure material, were now obtainable commercially. He did not know what experiments had been made on that form of superheater with other than seamless tubes, but in the earlier experiments, with welded tubes, the result was always failure. When Dr. Schmidt began to apply superheaters to locomotives, Mr. Rosenthal began to

Mr. Rosenthal.

apply them to Babcock-Wilcox boilers, and it might interest the members to know that the first superheaters built in accordance with his first design[1] of 1895 had been working night and day ever since; and, as far as he had been able to ascertain, they were as good as ever. One point referred to in the Paper was the quantity of oil used in the cylinders of the engine. Oil was absolutely essential when superheated steam was used in reciprocating engines. In the case of the locomotive the quantity did not matter, but such quantities as were mentioned in the Paper would not be permissible at all in stationary engines or for marine work. One thing in the Paper that surprised him considerably was the Author's statement that for the headers cast iron was used instead of the cast steel formerly employed. He did not know how long that experience had lasted, but his own experience was that the use of cast iron with superheated steam was disastrous, and for many years past he had used nothing but wrought steel for superheaters. The number of superheaters in use on locomotives had not been stated, but he gathered that it was very large. Since 1895 his firm had made and fitted to boilers, including foreign work, upwards of 20,000 superheaters, and at the present time there was hardly an installation carried out or a boiler of any capacity made that was not fitted throughout for superheating. According to the Paper, a saving of 30 per cent. had been recorded in a Midland locomotive, but it had been stated in the discussion that in other locomotives a smaller saving had been obtained, owing to the design of the engine being different. That result had been fully borne out in stationary practice. Before the small-tube superheater came into use the Schwoerer superheater obtained most prominence. It consisted of an arrangement of cast-iron ribbed pipes placed in a furnace, and from reliable experience of that superheater, obtained in some mills in Alsace, it was found in several instances that with an ordinary high-pressure single-cylinder engine economies of 30 per cent., and even more, were recorded. The practice that subsequently prevailed in various classes of reciprocating engines had shown that, with superheat of 120° or 150°, the utmost saving that could be obtained by superheating in an engine that used its steam as economically as it could be used — for instance, a triple-expansion condensing engine— amounted to only 10 or 12 per cent. The engine more generally used for stationary and marine work was the steam-turbine, in which the economy in using superheated as compared with saturated steam was very great. Very careful measurements with various

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[1] British Patent No. 6,221, of 1895.

Mr. Rosenthal. degrees of superheat had shown that the saving was, roughly, 1 per cent. for every 10° the superheat was increased above 80° or 90°. Of course there was a limit to what the material would stand. He knew of cases in which up to 1,000° of superheat had been recorded and where the superheaters had not stood the strain. It was beyond the power even of the best material to stand that. As far as his firm's experience went, the highest temperature which a superheater could be relied upon to stand for years was between 650° and 700°: the latter figure, as far as he could tell at the present time, was nearly the limit to which it was at all reasonable to go without considerable expenditure on maintenance. No mention was made in the Paper of the temperature of the gases surrounding the superheater-tubes when the locomotive was running, and it would be very interesting if that information could be supplied. In the superheaters made by his firm, when they were not directly fired there was always an intervening water-surface which took the sting out of the fire-gases, so that the tubes were not exposed to higher temperatures than between 1,200° and 1,500° F. Under those conditions it was found necessary to proportion the heating-surface of the superheater in such a way that there was a transmission of about 2,400 B.Th.U. per square foot of heating-surface per hour. It would be interesting to know what the rate of transmission was in a locomotive-superheater, because, so far as his experience went, it affected the durability of the superheater. He quite agreed with what the Author said as to the fluidity of superheated steam. In designing large steam-pipe ranges, whilst a speed of about 90 to 100 feet per second was reckoned on with saturated steam, it was found with superheated steam that one could safely go to 150 feet per second even with long lengths of pipe and allowing for bends. As to material, he would not put a copper pipe into a superheated-steam range under any conditions whatever: he never used copper with superheated steam. His remarks had not perhaps a direct bearing on the superheater as applied to locomotives, but they had an indirect bearing, in that they should tend to increase confidence in the application of superheaters, because they indicated to what a large extent superheating was used, and how universal it had become, quite independently of its application to locomotives.

Mr. Raven. Mr. VINCENT L. RAVEN quite agreed with Mr. Aspinall and Mr. Churchward as to the importance of superheated steam for locomotives; in his opinion nothing had been brought before the locomotive world which had effected economy in anything like the same degree. Of the few points in the Paper to which he desired to draw attention, the first was the influence of dampers upon superheaters. There was no doubt that with stopping trains, and also when engines were running with the regulator closed, a serious loss was sustained in the superheating economy. He considered that the damper-control gear referred to in the Paper was an ingenious plan for keeping the header-elements hot when the blower was off and for preventing them from overheating when the blower was on. After experimenting with the same object in view, the North Eastern Railway Company had dispensed with dampers altogether, the overheating of the elements being prevented by using circulating or by-pass valves, which came into action automatically as soon as the regulator was closed, and allowed a small quantity of steam to pass through the elements. That steam also passed through the cylinders and kept them hot while running with the regulator closed, as well as when the engine was standing. It also reduced the vacuum and compression when running with the regulator closed. That allowed the economy of the superheater to be maintained, and also enabled an acceleration to be obtained which would not be possible without keeping the heat in both the cylinders and the elements. By those means they had been enabled to do away with the dampers altogether, which he thought was a great advantage. The device he had referred to had been fitted for the last 12 months, and on examining the engines in which it had been tried he had found the elements in perfect condition, none of them having been burnt at all. The North Eastern Railway used tail-rods for the pistons in the cylinders, which were 19 inches in diameter. They had a large number of three-cylinder superheater high-pressure piston-valve engines, and were building others. These engines had cylinders 16½ inches in diameter, in which tail-rods were not used. They had also a large number of saturated-steam three-cylinder piston-valve engines, some with 15-inch and some with 16½-inch cylinders, and in these also tail-rods were not used. So far as packing was concerned, he had not found any more trouble with the superheater engines than with the saturated-steam engines. In both cases he used ordinary block metallic packing for the valve-spindle pistons, and spring-supported packing for the piston-rods of the cylinders, and no difficulty had been experienced with that class of packing. Very few of the engines were fitted with release-valves to allow the escape of trapped water: they were not found to be necessary on the superheater engines. He noticed that the Midland Railway had found it necessary to adopt ⅛ inch exhaust negative lap. That had been tried on the North Eastern, but it Mr. Raven.

Mr. Raven. was found by experiment that it was much better to have no exhaust negative lap, and they had even gone to the extent of using ⅛-inch exhaust lap instead. He did not think experience had shown that the North Eastern engines were at all sluggish, as it was possible with that exhaust lap to start an engine from York with a load of more than 200 tons and get to Darlington in 40 minutes, at an average speed of 66 miles per hour. That certainly did not support the view that the engines were sluggish. A large number of the heavy mineral-engines had superheaters, and he was confident, so far as they were concerned, that a ⅛-inch exhaust lap was a considerable advantage. The 4–6–0 engines, which were used not only for passenger-traffic but also for the fast goods-trains, had been found not to be giving the superheat that was desired, and the effect of doing away with a number of the smaller tubes in the engines had been tried. With sixty-four tubes blocked it had been found that the average temperature in the superheaters rose from 580° to 650° F. The North Eastern Railway Company were therefore building boilers with many fewer small tubes; in fact, the boilers that he was now putting into big mineral-traffic engines had only 90 small tubes instead of the 146 for which they were first designed. It was found that the boiler-pressure was admirably maintained with that heating-surface; also, the advantage of having much wider bridges for the tube-plate was obtained, and the result, no doubt, would be that the boiler-repairs would be less. With regard to the economy of superheating, it had been found on the North Eastern Railway that the saving of fuel obtained on express passenger-engines was about 20 per cent. That figure had been taken not over a few trips, comparing one engine with another, but over a considerable period of working. In 1911 they built twenty express three-cylinder high-pressure passenger-engines, ten of which were fitted with superheaters on the Schmidt system, the other ten being saturated-steam engines. The consumption of the engines in ordinary work had been carefully taken, and they had been working exactly the same link, so that a true comparison ought to be obtainable. Up to the present time it had been found that there was a difference of certainly 20 per cent. in the coal-consumption in favour of the superheater engines, while the repairs to the two classes of engines showed at least 50 per cent. in favour of the superheater engines, principally, of course, in boiler-repairs, the pressure in the one case being 180 lbs. per square inch and in the other 160 lbs. It had been found that the saving in the goods-engines was about 14 per cent., and in the mineral-engines about 10 per cent. It was

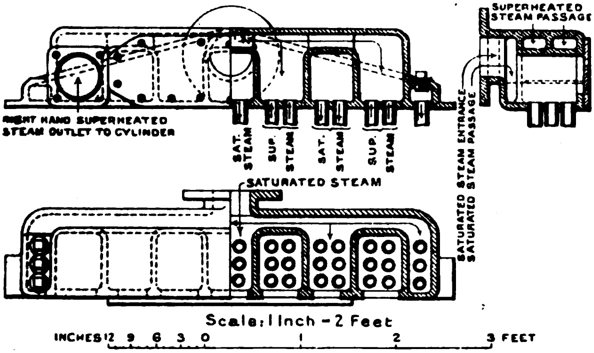
Mr. Raven.

exceedingly difficult to compare the results on one railway with the results obtained on another, because the experiments were not carried out in exactly the same way. There was no doubt that wind-pressure and difference of load might easily make a difference of 25 per cent. He would like to see some uniform basis adopted by railway-companies for carrying out their tests, so that clearer comparisons might be made than were possible at the present time. One company stated that it found a saving of 20 per cent., and another a saving of 14 per cent.; but it was necessary to have full particulars of the trials before one could judge whether those results were at all comparable. If some arrangement could be made to express the results in terms of the coal-consumption per indicated horse-power-hour, it would be a great advantage; and with the dynamometer-cars which most of the large railway-companies owned, and with which they were able to carry out trials, he did not think that should be impossible.

Mr. Smith.

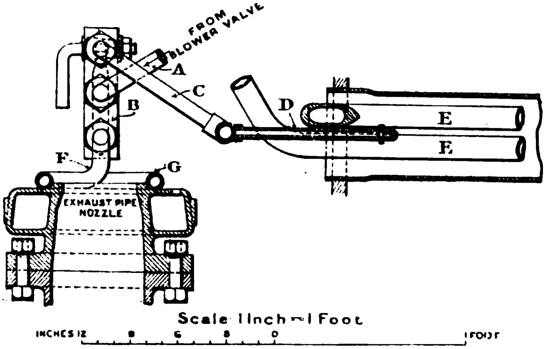
Mr. J. W. Smith, speaking on behalf of Mr. J. G. Robinson in his unavoidable absence, remarked that the savings in coal which had been effected on the Great Central Railway agreed very closely with those stated by the Author. Fig. 8, Plate 1, showed a type of header with top covers which possessed the advantage that any element could be removed without disturbing the others. With this type of header, when the covers were taken off it was difficult to see inside; and moreover, to facilitate getting the tube elements in and out of position, it was usually necessary to have a movable cover fitted on the smoke-box itself, which was inconvenient, to say the least. After 4 years' experience it had been found that it was not necessary to remove any of the elements, and for that reason Mr.

Figs. 24.


SUPERHEATED STEAM PASSAGE
RIGHT HAND SUPERHEATED STEAM OUTLET TO CYLINDER
SAT. STEAM
SUP. STEAM
SAT. STEAM
SUP. STEAM
SATURATED STEAM ENTRANCE
SATURATED STEAM PASSAGE
SATURATED STEAM
Scale: 1 Inch – 2 Feet
INCHES 12 9 6 3 0
1
2
3 FEET

Mr. Smith. Robinson had now adopted, as a standard, the header shown in *Figs. 24.* This header had the advantage that there was a front cover which could easily be removed, and to which access could be obtained by simply opening the smoke-box door. When the header-cover was removed, the ends of the tubes were quite accessible for inspection; while if at any time it was necessary to take tubes out, it was quite easy to do so. By using a dolly the lower end of which fitted in and on the end of the element tube, a second dolly placed above this with its upper end against the header-wall, and a wedge between the two dollies, the tubes could readily be driven out without damage being done either to them or to the header. He noticed that the end of the chimney in the Author's illustration of the Robinson superheater was incorrect; it was not used on any Great Central engine. One of the early difficulties experienced was the obstruction the dampers formed to the cleaning of the smoke-tubes, and, as was pointed out by the Author, if the smoke-tubes and superheater elements were not kept clean, it was soon found that the superheater was not of the same advantage as when first put in. After a number of experiments Mr. Robinson had devised the arrangement shown in *Fig. 25*, which was now fitted in Great Central engines. With this arrangement, when the blower was on, steam passed down the pipe A, into the interior of fitting B, from there through the pipe C, and thence into the nozzle-pipes D, which extended into the smoke-tubes centrally between the element tubes E, E. The size of the nozzle-pipe outlet was small (about $\frac{3}{32}$ inch in diameter), and the steam issuing from these pipes passed around the element tubes and through the smoke-tubes towards the fire-box end. These jets of steam were not strong

Fig. 25.



enough to blow into the fire-box, but they prevented the passage of gases through the large smoke-tubes from the fire-box to the smoke-box, and so obviated the overheating of the element tubes. At the same time steam passed from the fitting B, by pipe F, to the usual jet or blower-ring G, at the top of the blast-pipe. It would thus be seen that the ordinary blower and the "steam-jet retarder" acted in unison, the strength of the steam issuing from both sets of jets depending upon the opening of the blower-valve. It was found by using this arrangement of steam-jets that, in addition to stopping the passage of the gases through the large tubes from the fire-box to the smoke-box, it prevented the lodgment of soot on the elements and kept them clean. Altogether, the device had proved to be quite successful. The trouble experienced with the dampers had been obviated; the weight and cost of them had been saved; and the falling-off in economy, owing to the shed-men not being able to keep the tubes clean with the dampers in the way, had been prevented. **Mr. Smith.**

Mr. H. N. Gresley thought that a few results obtained on the Great Northern Railway might be interesting, seeing that that company was one of the earliest to adopt superheating in England. The experience gained had extended over the last 6 years, during which both goods and passenger superheater engines had been running. The very good results given by the Author were based on a few runs which had been specially recorded, and, generally speaking, such results were better than those obtained in everyday practice. Comparing the coal-consumption during 1913 of superheater engines with that of saturated-steam engines of exactly the same class, he had found that for the passenger-engines there was an economy of 14·7 per cent., and for the goods-engines 19 per cent. He agreed with Mr. Churchward that probably the inferior result obtained with the passenger-engines was due to the excellent design of the well-known Atlantic engine produced by Mr. Ivatt; those engines were so good that superheating did not improve them to the same extent as it improved the goods-engines. The saving in coal all round was 18·3 per cent., but against that figure must be put the increased consumption of oil, which was about 5 per cent. per 100 miles. Much more expensive oil had to be used, and as a result the cost of the oil was about 29 per cent. more with superheater engines than with saturated-steam engines. The total cost of oil was, of course, a small matter compared with the total cost of coal, and it only reduced the saving on the coal-consumption from 18·3 per cent. to 17·6 per cent. Tests similar to those made by the Author had shown a saving of about 30 per cent., but the figures Mr. Gresley had given were the all-round figures over the whole of **Mr. Gresley.**

Mr. Gresley. the year. So far as maintenance was concerned, he could not agree with the Author, as he found that the cost of maintenance of superheater engines was not less than that of saturated-steam engines; in fact, it was rather more, taking a period of 6 years. Mr. Raven had mentioned that he had found considerable economy during a period of 2 years. That had been found also on the Great Northern; but the tube-plates did not last as long with superheater engines as with saturated-steam engines, because the large flue-tubes tended to crack the bridges between the tubes. No doubt, having fewer tubes, and therefore thicker bridges, as advocated by Mr. Raven, would improve matters in that respect. There were one or two points in which the Great Northern practice differed from that of other companies. First, with regard to dampers, he did away with them 2 years ago, and, out of a total of 137 engines fitted with superheaters, 68 were not fitted with dampers. In 1913 those engines ran about 1,000,000 miles, and he had not seen a single case in which one of the elements had been burned. It therefore seemed to him that there was not much fear of serious trouble with the elements, and there was no necessity to adopt the expensive dampers or draught-retarders which were used on some railways. The temperature of the elements was kept down by placing a 4-inch or 5-inch snifting-valve on the header on the saturated side, so that directly the engine shut off steam, the snifting-valve opened and cold air was drawn through the element. This prevented it from getting overheated, and at the same time tended to prevent cold air from being drawn into the cylinders, which would result if the snifting-valves were fixed directly on the steam-chests. The absence of a damper also had the effect that when an engine was started after stopping the superheat rose much more quickly. To get a temperature of 600° F. with an ordinary goods-engine took 10 to 15 minutes if dampers were fitted, but without dampers it could be done in about 5 minutes, and that tended to increase the economy. With regard to flat valves, since March, 1912, the Great Northern had had engines running with Richardson valves, the wear of which was actually less in the superheater engines than in the saturated-steam engines, the reason being that there was forced lubrication under the valves, which more than counteracted the tendency to greater wear due to higher temperatures. The valves which were fitted in 1912 were in the engines that were running in express service at the present time. He saw no reason why, when a non-superheater engine came into the works for repairs to the tube-plates, new tube-plates of the superheater type should not be fitted.

Mr. Gresley. By that means the locomotive stock would be fitted with superheaters much faster than if they were fitted only to new engines and no conversions were made. A certain amount of difficulty had been experienced with the flue-tubes. Like Mr. Hill, he had had to screw them. They were screwed into the tube-plates, and a considerable amount of leakage was thus obviated. The Author advocated piston-valves of small diameter, no doubt owing to the fluidity of superheated steam. Mr. Gresley ventured to think that it was less difficult to get steam into the cylinders than to get exhaust steam out of them, and that a large piston-valve was required for that reason. If small valves were used, the exhaust was apt to be throttled too much and a free-running engine was not obtained. Could the Author give any information with regard to the superheating of compounds on the system called by the French *en cascade*—that was superheating not only the high-pressure steam, but also the exhaust from the high-pressure cylinder, before it went into the low-pressure cylinders—and the results obtained by that method. He gathered from the Paper that the Author only superheated the steam before it went into the high-pressure cylinder. With regard to the pyrometer and the Swindon superheater, Mr. Churchward thought the Swindon superheater attained a degree of superheat as high as, or higher than, the Schmidt. He gathered that Mr. Churchward had come to that conclusion from the appearance of the cylinders, and that he also thought that the pyrometers were not satisfactory. It seemed to Mr. Gresley that if pyrometers gave consistent readings of between 600° and 650° F. with the Schmidt superheater, and if the pyrometers also gave consistent readings of 550° to 580° F. on the Swindon superheater, it stood to reason that the Swindon superheater was getting a lower degree of superheat; but he might be wrong.

Mr. Halpin. Mr. Druitt Halpin observed that the boiler suggested by Jacob Perkins, to which the Author referred on p. 77, and which had been constructed by Mr. E. Herz, was the most remarkable boiler he had ever seen. He did not know of any article in the English language describing it, but it had been very fully described and illustrated in the *Zeitschrift des Vereines deutscher Ingenieure.*[1] It was merely a drum about 6 or 7 feet in diameter and 8 or 10 feet high, and there were small tubes about 1½ inch in diameter hermetically sealed, into which a very small quantity of distilled water was put before they were sealed. The furnace underneath the drum was of brickwork. The gases went up and flowed over the tubes

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[1] Vol. xxxviii (1894), p. 1300.

Mr. Halpin. in which the water was evaporated, and the heat was conveyed to the water in the boiler. The results given by that boiler were extraordinary. With very inferior Silesian coal, of a calorific value of only about 12,000 B.Th.U. per pound, the boiler showed a thermal efficiency exceeding 72·5 per cent. at the extraordinary rate of evaporation of 20·4 lbs. per square foot per hour. Its capability of absorbing heat in that way seemed to be altogether abnormal, because in the temperature of the gas, which by measurement was reduced from 2,912° F. to 932° F., there was a fall of 1,260° F. while the gas was passing over a smaller distance than 3 feet. With regard to the Author's description of his endeavours to get rid of the friction of the piston, Mr. Halpin hardly thought that was the right way to go about it. The late Mr. W. Schönheyder was the only engineer he knew of who, taking the bull by the horns, had made a piston float in the proper mechanical way. He did not see that any good could come of the endeavour to float a piston by using a tail-rod, because there was no proper bearing surface to carry the load. If plenty of surface were put in at the cross-head, and it were kept clean, the weight could be supported properly at that end; but the tail-rod end could not support any weight because it was working under a different set of circumstances. Leaving out for the moment the question of lubrication, because that came on both sides of the equation, it was necessary to remember that wear was the result of two factors, speed and pressure. With a tail-rod made in the ordinary way the weight bore on the bottom of the stuffing-box. The velocity of the tail-rod was the same all over. The maximum pressure was at the bottom, and at the sides there was no pressure at all. Under those circumstances he did not see how a tail-rod could do any good. When a piston was carried on a rod, the weight of the piston naturally deflected the rod. Mr. Schönheyder therefore bent the rod up bodily as much as it would deflect under the weight of the piston, so that when the weight of the piston came on it, it became straight. Outside at one end he had a cross-head, and at the other end a similar bearing; and with a reasonable amount of surface and proper lubrication the rod could be made in that way to take the load off the bottom of the cylinder if necessary. The Author seemed to dislike the usual practice of having the admission of steam between the piston-valve heads, so that the pressure was kept off the glands, on account of the extra complication of ports. When the cylinder was cast, all the complication of manufacture was done with for ever, and every advantage was obtained from keeping the steam from the glands. In the present instance, where engineers had to resort to

Mr. Halpin. the delicacy or strategy of air-cooled glands, he certainly thought it was better to put up with the slight extra original complication and keep the pressure off the glands; but that of course was a matter of opinion. Some valuable information was given in Figs. 20, Plate 2. He thought the chief value of the diagrams lay in the boiler-pressure and steam-chest-pressure lines, because they showed what a large fall of pressure there was. In the following Table the various pressures were expressed in terms of the boiler-pressure taken as unity: in one case the drop was about 40 per cent. The Author's diagrams enabled the drop to be analysed to a certain extent, because the drop was given from the boiler to the steam-chest, and then from the steam-chest to the piston. Between the boiler and the steam-chest the pressure must be lost either in the steam-pipe or in the regulator, and the loss of pressure between the steam-chest and the piston must be due to the wire-drawing through the ports on the valves. The Author went to a great deal of trouble and expense to obtain economy with the addition of anything between 17 cwt. and 2 tons to the weight of the engine, but Mr. Halpin did not think it could be very economical to add that weight to the engine and yet lose so much in fall of pressure. He did not mean to say that it was possible to get the whole theoretical pressure rightly followed up without perhaps undesirable complication, but he thought easy and simple means of largely reducing the fall could be found. *Fig. 26* was a diagram from a small engine he once saw, in which the boiler-

	No. 1.	No. 2.	No. 3.
Superheated:			
Initial steam-chest pressure	0·830	0·760	..
Initial cylinder pressure.	0·812	0·720	0·690
Fall of pressure between boiler and steam-chest	0·170	0·240	..
Fall of pressure between steam-chest and cylinder	0·018	0·040	..
Saturated:			
Initial steam-chest pressure	..	0·594	0·568
Initial cylinder pressure	0·664	0·542	0·495
Fall of pressure between boiler and steam-chest	..	0·406	0·432
Fall of pressure between steam-chest and cylinder	..	0·052	0·073

Mr. Halpin. pressure was about 150 lbs. per square inch, and, speaking from memory, the fall was of the order of 16 lbs. When it was altered the fall was about 2 or 3 lbs., as nearly as could be measured. It would be seen from the form of the diagram that there was an expansion-valve on the back of the distribution-valve, so that the compression remained constant. The whole of the alteration in reducing the fall of pressure was effected in less than an hour by cutting away the top edges of the expansion-plate ports, and making a *vena-contracta* entry for the steam, as shown in *Fig. 27*,

Fig. 26.

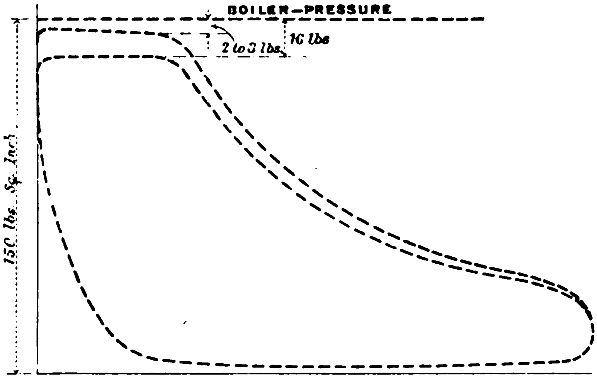
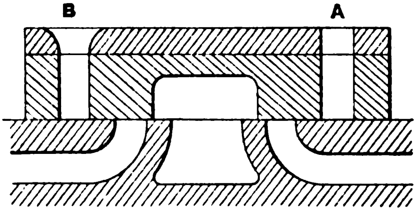


Fig. 27.



in which A was the original form of the port and B the form to which it was altered. In that simple way 14 lbs. out of the 16 lbs. pressure were retained. The principle was very clearly explained in a book by an American engineer, Mr. W. S. Auchincloss.[1]

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[1] "The Practical Application of the Slide Valve and Link Motion," etc., 4th ed., p. 24. New York, 1872.

Mr. Halpin. The motion of engines Nos. 992 and 998 was described in the Paper as a Deeley motion. He would not argue about patents, but he thought that those who had done similar work many years ago should at least be referred to. He understood that it was a Walschaert valve-motion, and that, instead of obtaining the differential motion from a return crank or from a return eccentric, it was simply obtained from the cross-head on the other side of the engine. He was quite willing to believe that Mr. Deeley schemed the motion independently, but more than 40 years ago he saw a number of engines of that kind, designed by a friend of his, the late Mr. Stevart, one of the chief engineers of the Belgian State Railways. One of the engines, which had been fully described and illustrated,[1] was put to work at Liége.

Mr. Simpson. Mr. Charles Liddell Simpson desired to narrate briefly the experience of Messrs. James Simpson and Company with regard to the reintroduction of superheating into this country. Professor Unwin informed them in 1894 that in Alsace, following up Mr. Hirn's very interesting experiments on the steam-consumption of steam-engines, Mr. Schwoerer had brought out a very successful superheating arrangement. It consisted of a series of cast-iron pipes about 8 inches in diameter. Inside there were longitudinal ribs; outside circumferential fins were cast. In a Lancashire boiler these superheaters were placed right at the back, immediately in the down-take before the gases passed into the side flue; and in a Babcock-Wilcox boiler, at the top, over the main tubes. His firm decided it would be a good thing to take up superheating, and accordingly they made arrangements to install one of these Schwoerer superheaters. As the members were aware, users were seldom disposed to allow experiments with new apparatus to be made, but his firm were fortunate in being permitted to put the first Schwoerer superheater into a Babcock-Wilcox boiler, at the Grand Junction Waterworks, through the courtesy of Mr. Walter Hunter, M. Inst. C.E., then the Engineering Director of those works. The boiler was supplying steam to a triple-expansion Worthington pumping-engine which had then been recently installed and tested. On making tests it was found that with 100° F. superheat at the engine stop-valve a saving of about 10 per cent. was obtained. The trials were repeated, and one day it was found that only 50° F. of superheat could be obtained at the engine stop-valve, giving an economy of only 5 per cent. The reason why only 50° of superheat could be obtained in the engine

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[1] *Engineering*, vol. xii (1871), p. 391.

Mr. Simpson. that day was that very small breeze and small coal mixed was being burned, and the blower had covered up the Schwoerer superheater to a large extent, so that the usual amount of heat was not getting round it. Later on experiments were made with high-pressure engines, and it was then found that a saving of as much as 30 per cent. could be obtained. One point that had been brought out by some of the speakers was that the saving due to superheated steam depended very largely on the type of steam-engine in which it was used. In a poorly-designed engine a much larger saving was obtained with superheated steam than would be obtained with a well-designed triple-expansion close-clearance engine. His firm decided that it would be better to adopt only a moderate degree of superheating. After the first experiments were made on the Grand Junction engine it was tried continuously for about a month with 12° F. of superheat at the engine stop-valve, and it then showed an economy of 15 per cent. His firm decided, however, that if superheating was to be applied to ordinary engines—engines having either flat slide-valves, Corliss valves, or drop valves—much less trouble would be experienced if a low degree of superheat were aimed at, rather than such a high degree of superheat as Dr. Schmidt had adopted. On a land engine using steam superheated to a very high degree specially-designed steam-cylinders, piston-valves, etc., were required, and everything else must be made to suit the temperature. It was also necessary to bear in mind that too much heat might be expended in highly superheating the steam, and that the saving of coal would not follow the saving of steam. In all the arrangements that his firm made for superheaters they always treated the superheater as part of the boiler, and if anything went wrong with the superheater the boiler had to be shut down; in other words, the engine stop-valve was the valve that controlled the steam passing from the boiler to the engine. In the case of the Author's locomotive-boilers he noticed that the stop-valve, or regulator, was placed in the boiler, and that the superheater was not always charged with steam. He felt sure that if the regulator-valve were placed on the cylinder side of the superheaters and the superheaters were always kept charged with steam, it would be found that the engine would run without any trouble. Mr. Raven had said that he did not use dampers, and that superheaters tried on engines without specially-designed steam-cylinders had been found to work quite satisfactorily. From the illustrations of special valves and of arrangements for allowing the steam into the superheater when the engine was standing, it seemed to him that the designer had put in a further complication, which might be avoided by keeping

Mr. Simpson. the superheater always charged with steam. Again, the ends of the superheater-tubes were far enough away from the firing end of the boiler for the tubes to take care of themselves. If the specimens of seamless tube exhibited had been used in an engine, very little deterioration in them was apparent. He was sure it would be agreed that a great deal of ingenuity had been shown on the part of the tube-makers in getting such close centres, for which, he believed, they were indebted to the system of acetylene welding, and also for thickening the ends of the tubes. He desired to ask the Author whether the engines whose trials were mentioned in the Paper were fitted with feed-water-heaters, because where superheating was being adopted it was just as well to arrange to put the water into the boiler as hot as possible. He always admired the huge locomotives at present used on British railways, many of them indicating more than 1,000 HP., and some of them, he believed, as much as 1,500 HP. Although an engineer might like to try many experiments on a locomotive, he must always think of the time when the locomotive had to start; it must be ready to start at a moment's notice and without any delay. He thought superheating in locomotives was a step in the right direction; it was surprising to him that locomotive-engineers had been so long in adopting it. The same remark applied to the reintroduction of superheating in marine engineering. Those who had read history knew that marine engineers such as John Penn, Humphrys, Tennant and others knew all about superheating, and it was only on account of the difficulty experienced with lubrication and the limitations of the materials then at their command that they discontinued its use.

Mr. Trevithick. Mr. F. H. Trevithick remarked that there seemed to be little left to say in support of superheating, but he thought something still remained to be said in regard to superheating in conjunction with feed-water heating. His experience of that matter on the Egyptian State Railways was that 200° of superheat reduced the coal-consumption from 45 lbs. to 36 lbs. per mile, that was, by about 20 per cent.; and by combining it with feed-water heating at 300° F., the coal-consumption was further reduced to 29 lbs. per mile, a saving of a further 20 per cent. In the arrangement used in Egypt the feed-water on its way to the boiler was heated by the exhaust steam to an average of 200° F., and it was afterwards further heated by the waste gases to an average of 300°. Those results showed, he thought, that there was a large quantity of heat going out of the chimney of the locomotive which might be utilized to advantage.

Colonel Crompton.

Colonel R. E. B. **Crompton** remarked that if he criticized the Paper on rather different lines from the previous speakers, it must be understood that he did so because he thought the present was an occasion when the subject ought to be looked at from a wider standpoint than the altered position of a few tubes, cocks, valves, baffles, and so on, which was the main subject of the Paper. Superheating had now been before engineers since certainly 20 years ago, when Mr. Rosenthal took orders from him and from other gentlemen for the introduction of superheaters in connection with Babcock-Wilcox boilers for large electric power-stations. The power-station engineers, who had then to design power-plant on a scale that had not been attempted elsewhere except at sea, took up superheating on a very large scale, and had never regretted it. They knew 15 years ago practically all that was now known about superheating, as it did not take more than 5 years to determine the economies that were possible with those forms of boilers and superheaters. The economies already obtained were large—considerably in excess of 25 per cent.—and he was sure that every designer of large power-stations would agree with him that without superheating they could not pay dividends. At that time they experienced all the hopes and fears, and received many of the solemn warnings of the difficulties they might expect with their engines, which the locomotive-engineers had apparently been troubled with during the last 4 or 5 years. It was true that locomotive-designers had progressed; they had fitted some of their locomotives with superheaters and had reduced the fuel-bills of these engines 25 per cent. They must be given credit for this first step; but they must do a great deal more before they would make the locomotive of the future take its place as the up-to-date traction unit of the railways. The railways would have to do something very much better in the way of economical running than they were accomplishing at present before shareholders and users would be satisfied. Three courses were open to them: the first was the much-talked-of electrification of the main lines; the second was the use of internal-combustion engines hauling lighter trains, or rail motor-cars and that kind of thing; and the third was the redesigning of the steam unit itself, not taking the locomotive that engineers had known all their lives, with its well-known standard boiler and fire-box, and attempting to tinker it to suit high-temperature steam, but going ahead like Heilmann did, who had ideas years ahead of his time. Locomotive-engineers must take their drawing-boards and design an up-to-date moving power-unit. They must follow the lines adopted by men who had improved power-units, not only in

Colonel Crompton.

generating-stations for power-distribution, but power-units at sea, such as those adopted by Sir Charles Parsons and the other men who had so successfully introduced the turbine. In that way, and in that way only, was there hope for such progress as had been reached in the big land and sea power-stations. He believed success was in front of anyone who had the pluck to tackle the problem of designing a moving power-unit for railways, which could take the place of the present locomotive and its tender. Much work had been done already. He would not go back over old times, but after the year 1900 much light was thrown on the possibilities of superheating steam, not merely to 500° or 600° F.—which simply meant heating saturated steam to a small extent, practically to keep it dry; that limit of temperature was soon seen to be insufficient: homogeneous steam-gas was necessary, to take the duty of the frothy cotton-wool stuff that came out of the chimney of a locomotive, which was not steam at all but a non-homogeneous and viscous fluid, difficult to get through the pipes and passages, and which scoured away the lubrication. It was not necessary to have very high pressure with superheated steam that was clean steam-gas. Many engineers had worked at this problem in a small way, among them Perkins, Serpollet, and Rollin White; these men had produced designs for small power-units which competed favourably with the internal-combustion engine. There were many present who knew that in a White engine the amount of liquid fuel used was only 25 per cent. in excess of the amount used in the internal-combustion engine. Where had anything been done of that description except in connection with central power-stations or marine work? Sir Charles Parsons and other engineers had made steam-units which approached in efficiency the internal-combustion engine unit, even in its best form—the Diesel engine. Why could not the same thing be done in connection with railway work? Why could not some man arise with pluck enough to throw the existing type on one side and start afresh? If one railway would not do it alone, why should not several railways combine and form an experimental fund to enable work of this important character to be carried out? In his opinion such design was a far easier matter nowadays than it was before the turbo-generator had been so much perfected. He suggested as the boiler unit a unit entirely built of tubes, in which the water—the working-fluid, coming from the feed-pump—would be accelerated by the heat of the fuel from a few feet per second up to the thousands of feet per second corresponding with steam at a temperature of 1,000°. That accelerated working-fluid could be passed into a turbine where

Colonel Crompton. the work put into it by the fuel in the form of acceleration could be taken out of it in the most efficient and economical way by deceleration. The turbine was usually a high-speed power-unit, but when coupled to an electric generator it could drive the wheels of a train. It appeared to him as an old electrical engineer who had spent some little time on traffic questions during his life that this was a straightforward solution of the problem, far preferable to main-line electrification and far preferable to the use of internal-combustion engines on railways. If locomotive-engineers wanted still to concentrate their hauling-power on the locomotive itself, they could gear down mechanically with the beautiful gearing that Sir Charles Parsons had lately introduced. There were other things to be borne in mind. For instance, they would not have to handle fuel as they had used it in the past. It ought not to be necessary to have a skilled stoker who could shovel the coal nicely into the corners of the fire-box. They would have to go back to T. R. Crampton's old notion of forcing in powdered fuel exactly as the power demanded steam. He referred to powdered fuel because he was not one of those who thought that relief would be obtained by the use of liquid fuel. There was not enough liquid fuel to go round as it was, and he resented attempts to persuade railways and other large power-users to use liquid fuel, as that increased the difficulty of the problem of those who were compelled to use it. Locomotive-engineers had, in his opinion, a straightforward problem to solve; they had to design a power-unit which would use powdered fuel, which would have a tubular boiler less difficult to construct than the present boiler, and which, with modern appliances and modern non-oxidizing steel alloys, could be made durable and easily repairable. They had already to their hand the turbo-generator which with steam-gas would give the 1,000 or 1,500 HP. required for driving a train. What sort of a train should it be? He suggested that it should be not more than half the weight of the present trains, and have four times the rate of acceleration—a train which would take proportionately less power to drive it, and would have an increase in braking power corresponding to what it had in accelerating power. He held up this picture for young men to work to. There were young men in the drawing-offices of the great railway-companies of England who had to win their spurs. He placed his suggestions before the Author, and asked him not to waste his time in designing cocks, valves, by-passes, and things of that sort, because such modifications could not lead to the great reform in design that was needed. So far it seemed that it was only possible to get a certain length in that direction, because loco-

Colonel Crompton.

motive-engineers were hampered and tied by old traditions, which must be entirely shaken off. They must abandon the idea that it was necessary to have 500 or 600 tons of train to carry 100 passengers. They ought to take a line from the metropolitan motor-omnibuses, which carried 34 passengers with 3½ tons of tare. He did not say it would be possible on railways to obtain figures proportional to those, but it would be possible to go far nearer than was the case at present. A great deal ought to be done with 100-ton or 150-ton trains if they were designed on modern lines.

Captain Sankey.

Captain H. RIALL SANKEY remarked that some years ago he pointed out that the Rankine thermal efficiency of a saturated-steam engine was rather higher than that of a superheated-steam engine, and he had prepared the following Table to illustrate that point. He had assumed in all cases that the superheat was moderate, namely 100° F., and that the exhaust of the engine was 1·5 lb. per square inch absolute. It would be seen that only in the case when there was the same steam-pressure was the superheated-steam engine very slightly more economical, theoretically, than the saturated-steam engine. The reason why the superheated-steam engine was practically more economical was that the losses were far less in one case than in the other; and, incidentally, that was the reason why a bad saturated-steam engine received more benefit from superheated steam than a good one, because the maximum attainable was much the same. The efficiency-ratio of a good saturated-steam condensing engine was, say, 0·62, and if that figure were multiplied into the Rankine thermal efficiency, namely 25·6, it gave 15·9 per cent. as the actual thermal efficiency of the engine. For a superheated-steam condensing engine a 0·8 efficiency-ratio was quite feasible, which, multiplied by the Rankine thermal efficiency, namely, 25·8, gave 20·6 per cent.; so that the improvement by superheating in this case was as 15·9 to 20·6, which was a

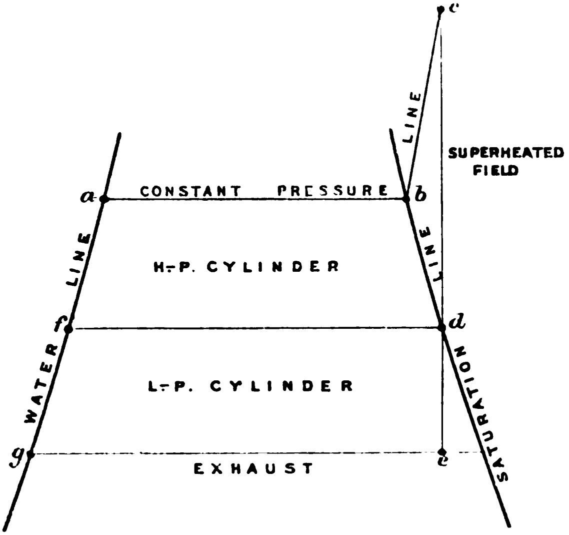
	Thermal Efficiency of Rankine Engine. Per Cent.			
	Non-Condensing.		Condensing.	
	Saturated	Superheated.	Saturated.	Superheated.
Same total heat, 1,200 B.Th.U. .	14·1	..	25·1	12·6
Same pressure, 160 lbs. per square inch absolute	14·7	15·0	25·6	25·8
Same temperature, 400° F.. . .	17·1	13·2	27·7	24·3

Captain Sankey. ratio of 1 : 1·295, or 29·5 per cent. The feed-water of the saturated-steam engine could be obtained by dividing the constant figure 2,545 by the thermal efficiency, 15·9, multiplied by the quantity of heat put into the steam per pound, which in that case was 1,119 B.Th.U. That gave a feed of 14·3 lbs. In the case of the superheated-steam engine more heat was put into the steam, namely, 1,170 B.Th.U., and the feed worked out to 10·55 lbs., that was to say, the superheated-steam engine required 10·55 lbs. of feed, and the saturated-steam engine 14·3 lbs. There was a tendency to look upon those figures as proportional to the relative economy of the two engines. If the ratio of those figures was taken it would be found to be 1·35, and that was not the true ratio of economy of the engines. In former days, when boilers began to be worked at high pressures, it was found they could not evaporate as many pounds of water per pound of coal as they did before, and boiler-makers invented the term "from and at 212°," because it was not commercially advantageous to make the boiler appear to be less economical from the point of view of the quantity of water evaporated. But in the case under consideration the reverse was the case, and he could not help thinking that the commercial advantage of saying that a superheated-steam engine required 10·55 lbs. of feed, as against 14·3 lbs. for a corresponding saturated-steam engine, was the reason why this method of comparison continued to be used. The Institution Committee on Steam-Engine and Boiler Trials had made a point of that matter in their Report, and the term "equivalent feed" had been devised, meaning the actual feed of the engine multiplied by the number of British thermal units required per pound of feed and divided by 1,100. In the present instance the feed for the saturated-steam engine was 14·3 lbs., the total heat per pound of steam was 1,203 B.Th.U., and the water-heat was 84°, which gave 1,119 B.Th.U. put into each pound of feed. In the case of the superheated-steam engine the total heat was 1,254 B.Th.U.; again the water heat was 84°, which gave 1,170 B.Th.U. per pound of feed. Therefore, according to the Institution rules the equivalent feeds were 14·54, and 11·22. From the coal point of view 11·22 was the true figure, and not 10·55, in the case of the superheated-steam engine. The ratio of 14·54 to 11·22 would be found to be 1·295, as before. It was a platitude to say that superheating improved the performance of steam-generators and especially reduced the losses in the steam-pipes, so that when it was adopted there was a gain not only on the engine, but also on the steam-generator and the steam-pipes. He desired to point out what seemed to him to be the

Captain Sankey.

ideal form of steam-engine. The two lines in *Fig. 28* represented the water and saturation lines of the θ ϕ chart, *a b c* being the constant-pressure line to which the engine was working, and *b c* being the portion of the constant-pressure line in the superheated field. The vertical line *c d e* represented the adiabatic expansion. The upper area *a b c d f* represented the high-pressure cylinder, and the lower area *f d e g* the low-pressure cylinder, and the point *e* showed the amount of water present in the steam at the exhaust in the low-pressure cylinder. For the ideal engine the two areas would be equal—that was to say, the same amount of work would be done in the high-pressure and in the low-pressure cylinder. Further, the high-pressure cylinder release was at *d* on the saturation-line, so that perfectly dry steam was introduced into the low-pressure cylinder. If the low-pressure cylinder were jacketed with boiler-steam it would be jacketed with steam which was at a much higher temperature than that entering the low-pressure cylinder, and there would be a considerable difference in temperature—probably more than 100° F. The result would be that the jacket side of the cylinder would be wet, and the inside of the cylinder would be dry, at all events at the beginning of the stroke. The effect of that would be that very little heat would be transferred

Fig. 28.



Captain Sankey. outwards from the cylinder; it would be transferred inwards from the jacket, and there would be little or no initial condensation. Thus, instead of the low-pressure cylinder being, as it usually was, inefficient, it became very efficient indeed. If the cylinders were mounted on top of the boiler, so that the steam condensed in the jacket could drip back again into the boiler, the only loss of heat in the jacket would be that due to condensation. He believed that the foregoing explained the extraordinary economy of the "over-type" of superheated-steam engines which had come from Germany, built by Messrs. Wolff and Lanz, and in England by Messrs. Garrett. Some time ago he had the opportunity of testing one of those engines, of 50 B.HP., and the coal-consumption was 1·21 lb. of Welsh coal per brake horse-power-hour, including air- and circulating-pumps. He did not think a result of that kind had been exceeded even in the best very large engines.

Mr. Pendred. Mr. L. **Pendred** noticed that the Author, following the example of other writers on the subject of superheater locomotives, had compared the quantity of coal burnt and water consumed in the engine. If 25 per cent. less water were required in a saturated-steam engine, 25 per cent. less coal should be burnt. But in a superheater a certain quantity of coal had to be burnt to put the superheat into the steam. In the figures given by the Author there were some curious anomalies. In engines Nos. 998 and 990 the coal saved was 23 per cent. and 24·5 per cent. respectively, while the water saved was 22 per cent. and 24·8 per cent., that was to say, the percentage saving of water was very nearly the same as the saving of coal. In No. 998, compared with No. 1043, the coal saved was 15 per cent. and the water saved was 17·5 per cent.; while in Nos. 1040 and 1039 the coal saved was 25·9 per cent. and the water saved was 22·3 per cent. In a goods-engine the coal saved was 14·3 per cent., and the water saved was 20·4 per cent. There must be some explanation of the curious way in which those figures occurred, and he would be glad if the Author could supply it. He also noticed that the Author had compared sister engines—that was, engines which had the cylinders of the same size—with saturated and with superheated steam. He thought that was not fair on the superheater engine. Superheated steam required a larger cylinder, both because the heat in the steam per volume of cylinder was less, and because more steam had to be got through in a given time. According to Messrs. Marks and Davis's Tables,[1] the total heat per cubic foot of saturated steam at 175 lbs. per square inch absolute was 460 B.Th.U., and with steam superheated to 250° it was only 370 B.Th.U. Hence a larger volume of steam must be used to do the same amount of work. In the Author's Tables for engines Nos. 998 and 990 a saving of 22 per cent. was shown in the quantity of steam or feed-water used: for every 100 lbs. of water used in the saturated-steam engine, only 88 lbs. was used in the superheater engine. But the specific volume of the saturated steam was 2·6, and of the superheated steam 3·6; it worked out, therefore, that for $100 \times 2 \cdot 6 = 260$ cubic feet of saturated steam $88 \times 3 \cdot 6 = 317$ cubic feet of superheated steam was used, so that for every mile run 23 per cent. more steam had to pass through the cylinders of the superheater engine, and they must either have a later cut-off or be larger. One point he desired to put to locomotive-superintendents on the present occasion was that they should endeavour to standardize the method of estimating the heating-surface in superheater locomotives. Some locomotive-superintendents added the evaporative surface (what used to be called the heating-surface) to the superheater surface, and called the whole thing the heating-surface. That, he considered, was wrong. Others—in Germany, for example—in measuring the area of the superheater-tubes took the outside of the tube, whereas in England as a rule the inside of the tube was taken, so that there was no harmony between the German and the English method. Again, in America—and he believed also on the Lancashire and Yorkshire Railway—the superheater surface was reckoned as having one and a half times the value it would have if it were simply evaporative surface. He thought it would be to the great advantage of all, and would help in the comparison of boilers, if some standard method could be adopted by locomotive-superintendents. Possibly the International Railway Congress might take the matter up at some time, and he believed there was an association in this country which could in the first instance take some steps in that direction. Mr. Pendred.

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[1] L. S. Marks and H. N. Davis, "Tables and Diagrams of the Thermal Properties of Saturated and Superheated Steam." London, 1909.

Mr. Siemens. Mr. ALEXANDER SIEMENS, Past-President, desired to call attention to the following statement made by the Author (p. 91): "It is desirable—although not the practice in the United States, where many locomotives are now fitted with superheaters—to provide a pyrometer, so that the driver may see what degree of superheat the steam has. These instruments are of two types—vapour-tension and electric thermo-couple—but neither seems yet to have reached absolute reliability." He thought, in that connection, the adage ought to be applied that science was measurement. If a driver did not see what he was doing with the super-

Mr. Siemens. heat he could not regulate it properly, and could not obtain the highest efficiency from his engine. The electrical pyrometer had been adopted elsewhere and had been found very reliable. The Prussian State Railways had 1,600 locomotives fitted with it, and there were at least 500 other locomotives so fitted in use in the Dutch East Indies and all over the world. In the United Kingdom the Great Northern Railway had fitted one locomotive with it. He simply wished to mention the point that the driver could not do justice to superheating unless he could see instantly and with perfect reliability what he was doing.

Mr. Jones. Mr. A. D. Jones said it was often thought that superheaters were not much good on stopping trains. He had recently looked through records of runs made by a stopping train drawn by a tank-engine fitted with a Schmidt superheater, in which the boiler-pressure was 160 lbs. per square inch. The train performed a journey of 66 miles with twenty-four intermediate stops, and he found that the maximum superheat between stations ranged from 670° to 610°, as measured by the pyrometer. The readings at stations whilst standing dropped to temperatures between 550° and 620°, according to the length of time the regulator had been closed. The maximum superheat between stations was usually reached in 1 to 2 minutes, in runs of 5 minutes; that was up to 640°. In the case where 670° was recorded it was reached in 4 minutes on a run of 8 minutes up a bank of 1 in 100. The pyrometer was fitted in the header, and the damper was operated by hand from the foot-plate. There was a snifting-valve on the saturated-steam side of the header. A record of that sort showed, he thought, that superheaters must be of considerable value on stopping services, and that the temperature in the elements did not fall so much as was sometimes believed. He had been very interested to hear Mr. Gresley mention that superheaters without dampers had been working on the Great Northern Railway for the last 2 years with no ill effects on the elements, because taking the dampers out of the smoke-box got rid of an obstruction, and also the loss of temperature when the regulator was shut was reduced, so that the maximum superheat was reached very quickly after the regulator was opened again. He had also been much interested to hear that Mr. Gresley and Mr. Hill considered it worth while to convert saturated-steam engines into superheated-steam engines. Mr. Hill's statement, that the Richardson flat balanced valve could be used, would assist in the conversion and render it cheaper, because not only was a saving effected in fuel, water, and boiler-repairs, but engines which had been converted would haul their load faster, or, if the load were increased, they would run at the same speed as before, so that to **Mr. Jones.** the operating department they became more efficient and valuable machines. At 7.30 that evening he had been talking to a driver who had just come up from Dover with the 5.20 boat train, which had about 300 tons behind the tender. The engine, a comparatively small one, had worked that service for a month without dropping a minute, whereas the engines which were working it previously—sister saturated-steam engines—were always losing time. He would be glad if the Author would state the number and size of the ordinary boiler-tubes in the engines described on pp. 98 and 99. Perhaps the Author had had opportunities of observing the effect of the hot gases on the ends of the superheater-elements, and the difference in the maximum degree of superheat, as well as the time taken to obtain it, after altering the length of the elements, that was, extending them nearer to or farther from the fire-box tube-plate. Speaking as an ordinary running-superintendent, he was quite sure that all his brethren wished that every engine were superheated. Superheater engines were no trouble whatever at the sheds, and they saved a great deal of trouble with the traffic-department. A permanent-way engineer told him a little while ago that he did not think superheating affected or interested him very much: but Mr. Jones held that superheating enabled locomotives to be constructed without excessive axle-loads, and he was sure engineers who were responsible for the track should be very glad of that, in view of maintenance-costs.

The Author. The AUTHOR, in reply, expressed his appreciation of the good discussion to which the Paper had given rise. He believed that the engine of which Mr. Bowen Cooke had spoken as having run 224,441 miles had been built in 1910, and its performance was one of the best testimonials that could be given to a superheater engine. Mr. Jones and other "running" men would appreciate the value of being able to obtain so much mileage in so short a time. Mr. Cooke, Mr. Druitt Halpin, and other speakers had raised the question whether a tail-rod actually caused the piston to float. He was perfectly satisfied that when the engine he had mentioned had bushes to the tail-rods lubricated from above, the piston did not float; and he was equally satisfied that with cast-iron bushes properly lubricated from underneath, the piston did float, as all wear of the tail-rod and its bush practically disappeared. With reference to Mr. Schönheyder's device, he thought it would be agreed that the piston-rods were quite stiff enough to hold the pistons without any appreciable deflection. With regard to the life of piston-rod packings, on the Midland Railway these lasted in

The Author. passenger-engines from one "shopping" to the next—say, 70,000 to 90,000 miles; but examinations of pistons and valves took place every 20,000 to 25,000 miles, and it might happen that during the time mentioned rings had been changed owing to breakage. He could not state the analysis of this packing, as it was bought from an outside maker, but he might say that they had tried the packing recommended by Mr. Stenning, with unsatisfactory results, although these might possibly be due to the way in which it was cast. Several speakers had mentioned the question of cast-iron headers and the effect of superheated steam on cast iron. Mr. Rosenthal had expressed surprise at the use of cast iron in connection with superheated steam; but the Midland Railway had used cast-iron headers for just over 2 years—perhaps longer than anyone else in this country—and up to the present there were no signs of any trouble with them. He would point out that the cast iron was exposed to a high degree of superheat only for a comparatively short time. If an engine ran with high superheat for 3 or 4 hours per day, it was doing very well, and probably giving the mileage which Mr. Cooke had mentioned. He had had some little experience with displacement lubricators, owing to the fact that on a line which the Midland had recently taken over there were several recently-built superheater engines which were fitted with them. They had not been at all satisfactory, it being found that they led to very considerable wear of the valves, etc. No particular fall in the superheat, such as Mr. Stenning had referred to, had been noticed. He knew that displacement lubricators were used extensively in the United States and in Germany, but there appeared to be something in English practice which prevented success from being obtained with them here. With regard to the indicator-diagrams, every care had been taken to give accurate reproductions of them. All locomotive men must have followed with much interest the remarks which Mr. Lelean and Mr. Raven had made with regard to the circulator which Mr. Lelean had described. It would no doubt be a great advantage to be able to start an engine from a station with the steam at a temperature of about 600° F. In view of what Mr. Stenning had said as to the higher temperatures which might be used in future, Mr. Clarkson's remarks with regard to packing were very interesting, although to locomotive men it seemed strange that he was in the fortunate position of being able to do without any liquid lubricant. Considerable interest always attached to the question of the use of D slide-valves not fitted with any relief arrangement. The experience he had had with slide-valves on a compound engine using 80° to 100° F. of superheat in

The Author.

the intermediate steam-chest made him envy the results that Mr. Hill was obtaining with a good deal higher temperature. The whole question seemed to be one of properly lubricating two working faces pressed heavily together. Where a balanced slide-valve was used, such as Mr. Churchward and Mr. Gresley employed, that did not seem to be a matter of great difficulty; but engineers who were associated, as the Author was, with lines where all the slide-valves were vertical and placed between the cylinders, were faced with a much more serious problem. On the Midland Railway the large tubes, which had been a source of difficulty to Mr. Hill, had given very little trouble. Up to the present time only one large tube had been taken out from the superheater engines fitted by the railway-company, and that failure was due to a defect in the manufacture either of the superheater element or of the tube itself, the exact cause being difficult to determine. It might be that some of the small differences in working which existed between all companies caused certain companies to be troubled in this way while the Midland was perfectly free. With regard to Mr. Stenning's remarks on the circulator, he would have liked to know how much steam it was necessary to pass through in order to get a really good result, because it would seem that if a very small quantity were used, there would be a tendency for the steam to short-circuit through certain of the elements, while if a large quantity were used there would surely be considerable loss. Mr. Stenning had rather questioned the figures which the Author gave at the commencement of the discussion with reference to the degree of superheat in the intermediate steam-chest of the compound engines. The intermediate steam-chest pressure when the temperature was taken was 60 lbs. per square inch, from which it was found that the temperature should be 308° F. for saturated steam, whereas it was 408° F., the difference being the 100° F. superheat which he had mentioned. He thoroughly agreed with Mr. Stenning as to superheater engines giving better results when worked hard as compared with saturated-steam engines, but this, of course, was due to a large extent to the engine as a whole having a greater capacity. There were, as Mr. Stenning had apparently found out, many factors governing the diameter and position of the blast-pipe top of a locomotive. The illustrations of the Swindon and Robinson superheaters, which had been criticized by Messrs. Churchward and Smith, had been supplied by the respective railway-companies. The use of electrical pyrometers, to which Mr. Siemens had referred, was a matter of great interest, which should receive more attention from instrument-makers than it had had hitherto. One of these pyro-

The Author. meters recently produced in the United States, in which the cold junctions were immersed in the boiler itself in order to keep them at a similar temperature, seemed to hold out considerable promise. Electrical pyrometers had been tried on the Midland Railway, but so far they had not been found to be perfectly satisfactory, the mechanism proving as a rule to be unsuitable for locomotive conditions. The pyrometers chiefly used in England at the present time were of the vapour-tension and mercury types. Mr. Churchward had seemed to doubt whether on the Midland Railway the temperatures mentioned were actually attained. There were two Midland engines fitted with Swindon superheaters, and the same pyrometers had been used on these as on the engines fitted with Schmidt superheaters, so that, as Mr. Gresley had pointed out, the results were comparable. It had been found with the Schmidt superheater that the average temperature when the engine was running well rose to about 620° F. at 160 lbs. per square inch steam-pressure, this being equivalent to 250° F. of superheat. With the Swindon superheater under similar conditions, the boiler in that case being worked at 175 lbs. per square inch, the temperature rose to 560° F., or a superheat of 183° F. Every possible precaution was taken to check the pyrometers. They were tested before and after the trials, against a standard pyrometer, which in its turn was tested periodically by the well-known method against certain definite melting-points. Although it was found that the pyrometers did vary, it was only a matter of a few degrees, which would not materially affect the results obtained where the difference of superheat was about 70° F. The approximate increase in weight mentioned in the Paper as being the result of superheating an engine included a larger smoke-box, new cylinders, and the provision of various additional mechanism; whereas on the Great Western Railway it did not include, he believed, any alteration other than fitting the superheater to the boiler. It would be noticed that this was borne out by the weights given in the Appendix for engines Nos. 992 and 1039, as against Nos. 998 and 1040. Dealing, however, with engines built in the same way, and with simply the increase of weight due to the superheater, as in the case of engines Nos. 484 and 489, the difference of weight agreed closely with that mentioned by Mr. Churchward. The figures given by Mr. Churchward with regard to the saving of coal were interesting and encouraging. In reply to Mr. Rosenthal, he believed that a number of engineers were using superheaters without dampers, and Mr. Gresley had stated that he was obtaining satisfactory results. He believed that seamless steel tubes were used exclusively for superheater elements. He

The Author.

presumed that when Mr. Rosenthal spoke of the quantity of oil used in stationary and marine engines he took into account that collected from the steam before it passed into the condenser: in a locomotive the oil passed away with the steam into the atmosphere. Were it possible to recover it economically, locomotive-engineers would be only too glad to give the matter attention. He could not say how many locomotives in the world were fitted with superheaters, but he thought the number must greatly exceed the 20,000 mentioned by Mr. Rosenthal as fitted to other boilers. The experimental plant at Altoona, in the United States, had shown a temperature of about 1,200° F. around the superheater elements. Experiments in England had shown that the rate of heat-transfer might be as high as 3,000 to 4,000 B.Th.U. per square foot of superheater surface per hour, but that, of course, would only be for a comparatively short time. Mr. Raven's statement regarding the excellent result obtained with engines having $\frac{1}{2}$-inch exhaust lap was very interesting, but the Author's experience did not agree with his on that point, although, of course, the design of the valve-gear would affect the result somewhat. Mr. Raven's experience of the use of fewer small tubes was also extremely interesting: the gain by having wider bridges for the tube-plates would be very considerable. Mr. Raven and Mr. Gresley had somewhat criticized the method of carrying out tests. The object of making those referred to in the Paper had been to show exactly what saving was possible. The savings mentioned had been confirmed in actual running practice, and he held that to show what could be done afforded a basis for determining what should be done in ordinary working. A uniform basis of testing was undoubtedly desirable, and doubtless the matter would be considered in the proper quarters; but, as Mr. Raven would realize, it was a matter of considerable difficulty when the tests were made on different railways. With regard to the Robinson blast-retarder, it must not be forgotten that anything using steam had to be carefully watched, lest it should become a source of loss. Mr. Gresley's remarks were specially interesting in view of the length of time superheating had been practised on the Great Northern Railway. The Author could only say that the tube-plates of the engines which had been fitted with superheaters at Derby were in good condition after 2 years' running, and showed no tendency to crack between the bridges. With regard to the size of the piston-valves, the Author fully appreciated the difficulty of getting exhaust steam out of a cylinder; the diagrams (Figs. 19, Plate 2), however, indicated how much more freely the exhaust cleared itself

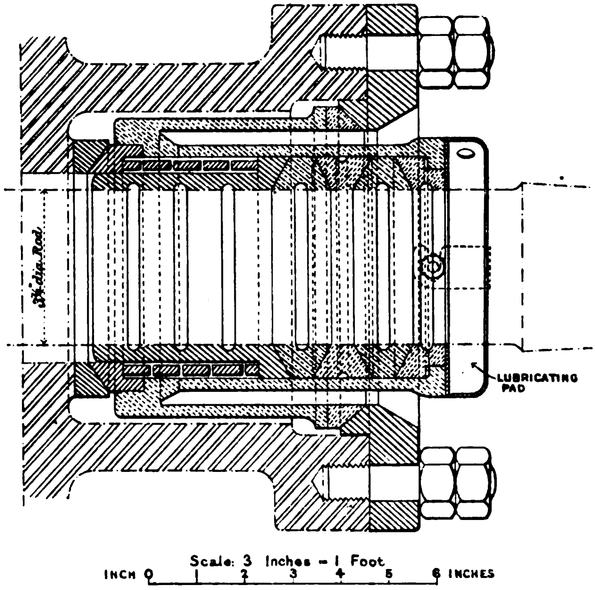
The Author. with a superheater engine than with a saturated-steam engine. He regretted that he had no information with regard to the cascade method of superheating compounds, although he knew that system was employed on the Eastern Railway of France. Mr. Druitt Halpin had questioned the practice on the Midland Railway of having the exhaust between the piston-valve heads. In addition to the cylinder-casting being simpler, as pointed out in the Paper, the Author thought another advantage lay in the easier exhaust which it gave. The fall of pressure to which Mr. Halpin had referred was due to the small amount the regulator was opened in order to work the train at this particular time. To have the regulator on the cylinder side of the superheater elements, as Mr. Simpson had suggested, would give certain advantages, but there were serious objections that would more than counterbalance those advantages. In the engines which were the subject of the trials mentioned in the Paper, feed-water heaters were not fitted. The Midland Railway had some engines fitted with feed-water heaters, and trials were being carried out with them. He thought perhaps it was the remembrance of the difficulties which occurred up to the year 1870 that made locomotive-engineers appear slow in trying superheating again, and caused them to lag a little behind their colleagues who dealt with stationary work. With regard to the remarkable words which had been spoken by Colonel Crompton, he fully appreciated the liability of locomotive-engineers to get hide-bound and tied up when dealing with locomotive matters. It must be remembered that a locomotive-engineer was restricted by two things which did not affect an engineer dealing with stationary practice: one was the loading-gauge, the other was the under-bridges. In considering the suggestions Colonel Crompton had made, it should be borne in mind that the existing locomotive-engine was, with the exception perhaps of the motor-car, the lightest and most compact power-station in the world. When it was remembered that in a 1,000-HP. locomotive there was no chimney to speak of, and a certain quantity of steam had to be used for producing the draught, he contended that the locomotive, inefficient as it might seem, gave very satisfactory results, in spite of many disadvantages. He could not help thinking, however, that if, as Colonel Crompton had said, a fresh start would have to be made, the suggestion to use powdered fuel in the cylinders instead of transmitting its energy through a boiler, was a great deal nearer the way in which improvements might ultimately be obtained than the arrangement Colonel Crompton had put forward. Again, if a turbine was to be used to greatest advantage it should be fitted with a condenser, and Colonel Crompton knew what difficulty had arisen in the early days of steam motor-lorries when an attempt was made to fit one of these. With regard to the weight of trains per passenger, the figures which Colonel Crompton had mentioned were, he thought, considerably on the high side. No one regretted more than railway-engineers did that modern requirements had led to so large an increase in the weight per passenger. It must be remembered that the speed and the conditions under which railway-trains ran were very different from those of metropolitan omnibuses. It would seem from the figures Captain Sankey had given that with compound superheater engines there would be an advantage in steam-jacketing the low-pressure cylinder. With regard to the suggestion that the cylinders might be mounted on the top of the boiler, in a locomotive the designer was tied considerably by the gauge and the method of transmission to the wheels. The discrepancies which Mr. Pendred had pointed out between the savings of water and of coal had been noted, and the Author regretted that he could not furnish any satisfactory explanation of them. The want of uniformity in the method of estimating heating-surface in superheater locomotives was, as Mr. Pendred had said, very confusing, but no doubt the attention drawn by him to the matter would cause the subject to be gone into. In reply to Mr. Jones's question, the numbers and sizes of the boiler-tubes in the engines described on pp. 98 and 99 were:— The Author.

Engine Number.	Number of Fire-tubes.	External Diameter.
		Inches.
489	148 21	1¾ 5⅛
484	254	1¾
1040	148 21	1¾ 5⅛
1039	216	1⅞
998	148 21	1¾ 5⅛
992	249	1¾
1043	216	1⅞
3835	148 21	1¾ 5⅛
3185	242	1¾

Correspondence.

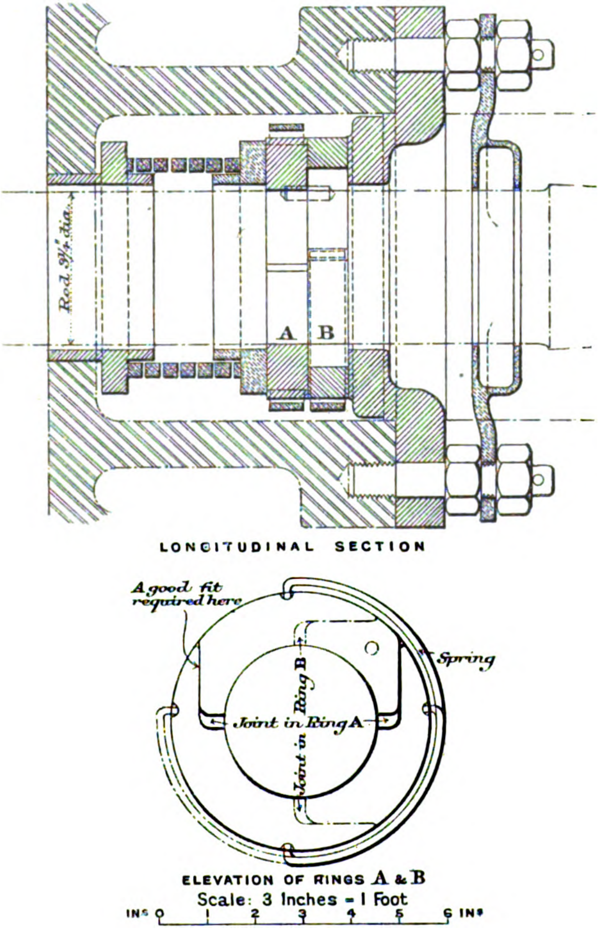
Mr. Adams. **Mr. John H. Adams**, of Stoke-on-Trent, observed that superheated steam could not be used to full advantage unless the packings would withstand the high temperatures attained in the modern superheater locomotive, and his experience on the North Staffordshire Railway was that the white-metal packing-rings gave a certain amount of trouble. A number of locomotives on that railway were fitted with the Schmidt superheater and had the Schmidt type of air-cooled piston-rod packing (*Fig. 29*), which answered its purpose fairly well, but was rather costly to make; further, its various parts took considerable time to assemble in the stuffing-box, particularly

Fig. 29.



Mr. Adams. where running-shed fitters were but little acquainted with this style of packing. He had therefore experimented in a saturated-steam locomotive with a packing made of cast-iron rings (*Fig. 30*), and the results had been so astonishing that—after 6 months' trial, during which time the packing required no attention—he had fitted one cylinder of a superheater engine with a cast-iron packing,

Fig. 30.


Rod 3¼" dia.
A
B
LONGITUDINAL SECTION
A good fit required here
Spring
Joint in Ring B
Joint in Ring A
ELEVATION OF RINGS A & B
Scale: 3 Inches = 1 Foot
INS 0 1 2 3 4 5 6 INS

Mr. Adams. whilst the other cylinder retained the Schmidt packing. After running about 7,000 miles the white-metal rings in the Schmidt type of packing had to be renewed, but the cast-iron packing required no attention whatever, and remained absolutely steam-tight. A remarkable point was that with the cast-iron rings the wear of the piston-rods was practically nothing, a fine smooth surface being maintained on them. With white-metal packing it was not at all uncommon for particles of grit to become embedded in the comparatively soft metal, and to cause considerable grooving in the rods. Each cast-iron ring was made in two pieces, one sliding into the other, and these were held in position by a flat steel spring. The steam-pressure in the stuffing-box, outside the rings, also tended to adjust the latter to the rod. *Fig. 30* showed that the various parts of the cast-iron packing were simple, cheap to manufacture, and easily fixed in position, and no special lubrication was required for the stuffing-boxes. He would, therefore, as occasion permitted, fit all his superheater engines with this packing.

Mr. Ashton. Mr. H. ASHTON, of Munich, observed that on the Bavarian State Railways eleven four-cylinder compound locomotives had been fitted with the Pielock superheater, and 325 four-cylinder compound and two-cylinder simple locomotives with Schmidt smoke-tube superheaters. The Schmidt type had proved superior to the Pielock. The temperature of the superheated steam obtained with the former was 662° F., and with the latter 536° F. To control the gases flowing through the smoke-tubes, nearly all the locomotives were fitted with Schmidt superheater dampers, which shut automatically with the closing of the steam-regulator, and could also, on the majority of the engines, be worked by hand. Both ends of the superheater elements were expanded into a flange which was attached by a bolt to the header. The joints between the flanges and the header were made with copper rings and asbestos filling. The smoke-tubes were, as a rule, provided with copper sleeves at the fire-box end, and were beaded over in the smoke-box. The headers were of cast steel with a tensile strength of 23·5 to 27·9 tons per square inch, or of cast iron (with steel added) with a tensile strength of at least 11·43 tons per square inch. Relief-valves were provided on the steam-cylinders, and on the later engines anti-vacuum valves or by-passes were also fitted on the cylinders. The steam-distribution was effected by cast-iron piston-valves with spring packing-rings. The high-pressure valves had inside, and the low-pressure valves outside, admission. The larger valves weighed about 220 lbs., the smaller valves about 44 lbs. The wear on them was light, and after 2 years' running they were still reasonably steam-tight. The fouling consisted chiefly of encrusted oil residues, which, however, were soluble in petroleum. No seizing of the piston-valves had been observed. The pistons were of cast iron or cast steel. The high-pressure piston-rods had split packing-rings of cast iron, while the rings of the low-pressure piston-rods were of white-metal. For the parts working under steam-pressure the lubricant employed was superheated-steam cylinder-oil, which was made from the finest mineral oil, and must be free from water and acid, and thoroughly purified. The flash-point was determined either in an open vessel or in the Pensky-Martens apparatus. In the former case it should not be lower than 608° F., and in the latter not lower than 572° F. The viscosity, according to Engler (referred to water at 68° F. as unity) should be, at 212° F., between 5 and 7, and at 356° F. at least 1·5. The oil should be so far able to withstand the influence of cold that after 1 hour's cooling to 0° C. there should be no sign of congelation. Among other lubricating pumps, the Friedmann type had proved satisfactory, and these pumps mostly had four to six oil-delivery points. In the two-cylinder engines every slide-valve and piston had one oiling-point, while in the four-cylinder compounds each high-pressure valve was oiled at three points, each high-pressure cylinder at one point, and each low-pressure cylinder at four points. For determining the temperature of the superheated steam in the high-pressure steam-chest, pyrometers of the mercury, thermo-electric, and tension types were employed. The mercury pyrometers required frequent and costly repairs, and would not be fitted in future. The thermo-electric type had proved satisfactory so far, temperature-variations being indicated immediately. Sufficient experience of the tension-pyrometer was not yet available. The superheater-tubes were cleaned after every run by blowing them out with compressed air. In Mr. Ashton's experience steam tube-cleaners had not proved satisfactory. Mr. Ashton.

Mr. Asselin.

Mr. G. Asselin, of Paris, stated that on the Northern Railway of France the economy effected by the use of superheating was far from attaining 30 per cent., as indicated by the Author, and in fact reached only 15 per cent.

Mr. Biernacki.

Mr. R. K. Biernacki, of Lahore, stated that on the North Western Railway of India four engines had been fitted with Schmidt superheaters, of which two were passenger- and two goods-engines. They had been working only since January, 1913, and he

Mr. Biernacki. was therefore not in a position to give much useful information on the subject; but the results so far had been satisfactory, and he had ordered ninety-five new locomotives, both passenger- and goods-engines, with Schmidt superheaters, while he had also ordered two passenger-engines with Robinson superheaters, for comparative trial. The four engines with Schmidt superheaters had been run in regular everyday work against similar engines with saturated steam, on the same services. The saving in fuel, in favour of the superheater engines, had averaged 19 per cent. with the passenger-engines (4–4–0) and 7 per cent. with the goods-engines (0–6–0). Special trials had shown larger savings. There had been also a saving of about 8 per cent. in oil-consumption, which was due to the use of mechanical lubricators. The saving in water had not been accurately recorded, but was approximately 30 per cent. The superheater engines had proved themselves capable of taking loads about 20 per cent. heavier than those of saturated-steam engines of the same types. With regard to repairs, two flue-tubes in one of the superheaters started leaking and were expanded. They had given no trouble since. The boiler-pressure was 160 lbs. per square inch, as against 180 lbs. per square inch for the saturated-steam engines of the same type. Piston-valves were employed and had given no trouble, and no difficulty had been experienced with lubrication. Relief-valves 1½ inch in diameter were fitted. It had been found that, when running without steam, ashes and dirt were drawn into the steam-chests and cylinders. Fowler-Anderson automatic by-pass valves would therefore be fitted to the next superheater engines, in addition to the relief-valves. A very important point was that the lower boiler-pressure with superheated steam would reduce the cost of repairs and add materially to the life of the boiler. In future probably all his new passenger-engines would be fitted with superheaters, and about one-half of the goods-engines. He had also tried the Phœnix smoke-box superheater, but the results had not been satisfactory.

Mr. Bohan. Mr. W. J. Bohan, of St. Paul, Minn., U.S.A., forwarded the following particulars of the results of tests of two of the latest types of "Mikado" goods-engines on the Northern Pacific Railway, which had been equipped with the top-header type of Schmidt superheater. Experience with this device had been very satisfactory, particularly on the larger engine. The change from gaskets to ball joints on the headers had resulted in a decided improvement so far as repairs and leakage were concerned.

Mr. Bohan.

NORTHERN PACIFIC RAILWAY COMPANY: SUPERHEATER TEST REPORT.

Seattle Division: Tacoma to Lester.

Particulars of Engine.

Engine	No. 1,522	No. 1,673 (*Fig. 31*, p. 100)
Cylinder diameter, right	$24\frac{1}{32}$ inches	$27\frac{1}{2}$ inches
,, ,, left	$24\frac{1}{32}$,,	$27\frac{1}{2}$,,
Driving-wheels, diameter	$61\frac{5}{32}$,,	$62\frac{7}{8}$,,
Kind of superheater	None	Schmidt

Average Results of Six Tests without Superheater and Five Tests with Superheater.

			Percentage of Saving Superheater over Non-Superheater.
Distance . . . Miles	62·355	62·31	
Number of cars, loaded	25·33	25·40	
,, ,, total	27·17	25·40	
Weight of cars, loaded . . Tons	1,017·33	1,047·20	
,, ,, total . . ,,	1,046·67	1,047·20	
Number of stops	8·83	7·60	
Schedule running-time	5 hrs. 30 min.	5 hrs. 30 min.	
Actual running-time	4 ,, $50\frac{1}{6}$,,	4 ,, $8\frac{1}{5}$,,	
Actual time standing	1 ,, $13\frac{5}{6}$,,	1 ,, 23 ,,	
Total time on road	6 ,, 4 ,,	5 ,, $31\frac{1}{5}$,,	
Average miles per hour on road	10·28	11·28	
,, ,, running	12·89	15·06	
Average drawbar pull . . Lbs.	17,572·5	17,252·6	
,, ,, horse-power	604·3	693·8	
Coal burned, running . . Lbs.	24,920·8	21,674	
,, ,, standing . . ,,	680·8	591	
Total coal burned . . . ,,	25,601·6	22,265	
Water evaporated . . . ,,	118,250	89,626	
Actual water evaporated per lb. of coal . . ,,	4·62	4·02	−12·9
Average feed-water temperature	45° F.	42·4° F.	..
Equivalent evaporation from and at 212° F.	5·67	4·92	−13·2
Average steam-pressure . . Lbs.	188·7	142·8	..
Average moisture in steam . . Per cent.	2·54	1·84	27·5
Average superheat at steam-chest	None	176·8° F.	..
Number of ton-miles	65,272	65,253·4	..
Ton-miles per ton of coal, running	5,238·3	6,021·9	14·9
,, ,, ,, total	5,099·0	5,681·5	14·9
Water per ton-mile . . . Lbs.	1·817	1·373	24·4
Coal per drawbar, horse-power-hour, running . . ,,	8·52	7·75	9·1
Water per drawbar horse-power-hour, running . . ,,	39·39	30·40	22·8
Temperature	45° F.	41·6° F.	..
Average steam-chest temperature	366·6° F.	538·8° F.	..
Coal per 1,000 ton-miles, running . . Lbs.	381·8	332·1	13·0
Coal per 1,000 ton-miles, total . . ,,	392·2	341·2	13·0

Mr. Bohan.

NORTHERN PACIFIC RAILWAY COMPANY COMPARATIVE TEST:
AGAINST SAME ENGINE WITH

(*Average of Three*

		Eastbound.	Westbound.
Distance	Miles	94·67	96·386
Total ton-miles		179,824	265,645
Number of stops		13·6	8·3
Time on road		10 hrs. 5⅓ min.	8 hrs. 31⅓ min.
,, standing		3 ,, 12⅓ ,,	2 ,, 44⅓ ,,
,, running		6 ,, 53 ,,	5 ,, 47 ,,
Average miles per hour on road		9·38	11·31
,, ,, ,, running		13·75	16·67
Average drawbar pull	Lbs.	16,700	11,602
,, ,, horse-power		615·8	515·6
Total coal burned	Lbs.	19,038·3	14,718
Coal burned, standing	,,	833·3	683·3
,, ,, running	,,	18,205	14,034·6
Water evaporated	,,	148,383·3	120,916·6
Actual water evaporated per lb. of coal	,,	7·79	8·22
Average feed-water temperature		54·3° F.	52° F.
Equivalent evaporation from and at 212° F.		9·43	9·95
Average steam-pressure	Lbs.	148·6	149·3
Average moisture in steam at dome	Per cent.	3·46	3·82
Average steam-chest temperature[1]		509·3° F.	501° F.
,, superheat at steam-chest[2]		147·6° F.	135·6° F.
,, smoke-box temperature		584·3° F.	579° F.
Ton-miles per ton of coal, running		19,755·5	37,855·7
,, ,, total		18,890·8	36,098·0
Coal per 1,000 ton-miles, running	Lbs.	101·2	52·8
,, ,, ,, total	,,	105·9	55·4
Water per ton-mile, total	,,	0·825	0·455
Coal per drawbar horse-power-hour, running	,,	4·29	4·71
Water per drawbar horse-power-hour, running	,,	33·47	38·61
Temperature		57·6° F.	53·3° F.

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[1] No temperature taken within 10 minutes of start from standstill.

Mr. Bohan.

W1 ENGINE NO. 1,661 (*Fig. 31*) WITH 150 LBS. BOILER-PRESSURE
160 LBS. BOILER-PRESSURE.

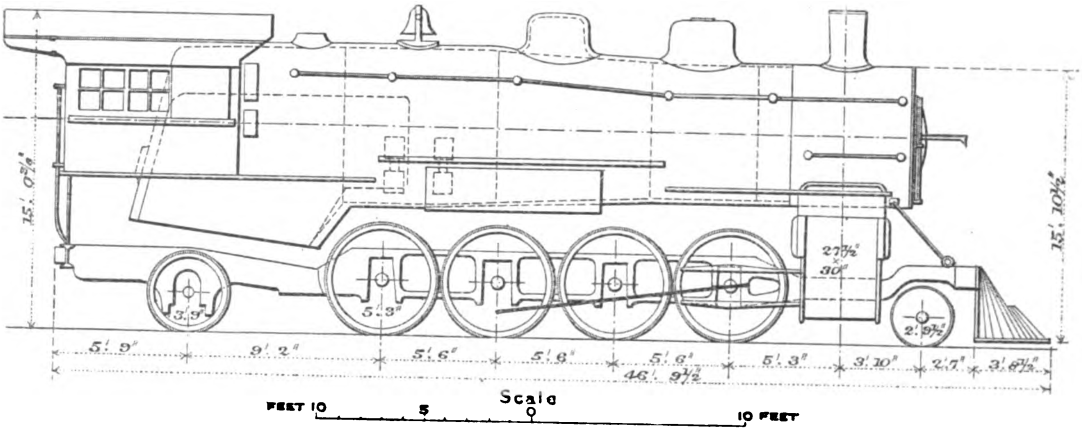
Tests in Each Case.)

Eastbound.	Westbound.	Percentage Saving 160 Lbs. over 150 Lbs.		
		Westbound.	Eastbound.	Total.
98·646	96·386	..	..	..
203,959·3	234,788	..	..	..
12·6	6	..	..	..
10 hrs. 50 min.	5 hrs. 52⅔ min.	..	..	..
3 „ 28 „	0 „ 55 „	..	..	..
7 „ 22 „	4 „ 57⅔ „	..	..	..
9·11	16·40	..	..	..
13·39	19·43	..	..	..
17,226	10,490	..	..	..
615·2	543·5	..	..	..
20,872·3	13,175·3	..	..	..
728	194·3	..	..	..
20,144·3	12,981	..	..	..
161,350	95,666·6	..	..	..
7·73	7·26	− 0·8	−11·6	− 6·2
48·3° F.	48·3° F.	..	..	..
9·43	8·86	− 0·9	−14·2	− 7·6
158·6	159	..	..	..
4·52	4·96	−30·6	−29·8	−30·2
518° F.	512° F.	1·7	2·2	2·0
148·3° F.	142° F.	0·5	4·7	2·6
599° F.	594·3° F.	− 2·5	− 2·6	− 2·6
20,249·9	36,174·1	2·5	− 4·4	− 1·0
19,543·5	35,640·6	3·5	− 1·3	1·1
98·8	55·3	2·4	− 4·7	− 1·2
102·3	56·1	3·5	− 1·3	1·1
0·791	0·407	4·1	10·5	7·3
4·45	4·81	− 3·7	− 2·1	− 2·9
34·36	34·96	− 2·7	9·5	3·4
45·3° F.	48° F.	..	..	..

[1] Degree of superheat taken above temperature corresponding to pressure.

Mr. Bohan.

Fig. 31.


15′ 0¾″
15′ 10¾″
27½″ × 30″
3′ 9″
5′ 3″
2′ 9½″
5′ 9″
9′ 2″
5′ 6″
5′ 6″
5′ 6″
5′ 3″
3′ 10″
2′ 7″
3′ 6½″
46′ 9½″
Scale
FEET 10
5
0
10 FEET

NORTHERN PACIFIC RAILWAY: CLASS W1 "MIKADO" GOODS-ENGINE (NO. 1,661).

Valve-gear	Walschaert.
Grate-area	43·5 square feet.
Superheater	Schmidt.
Total weight of engine	118 tons 8 cwt.
Number of tubes	228 and 27.
Size of tubes	2 inches and 5⅜ inches.
Heating surface	2,832 square feet.
Superheating surface	465 " "

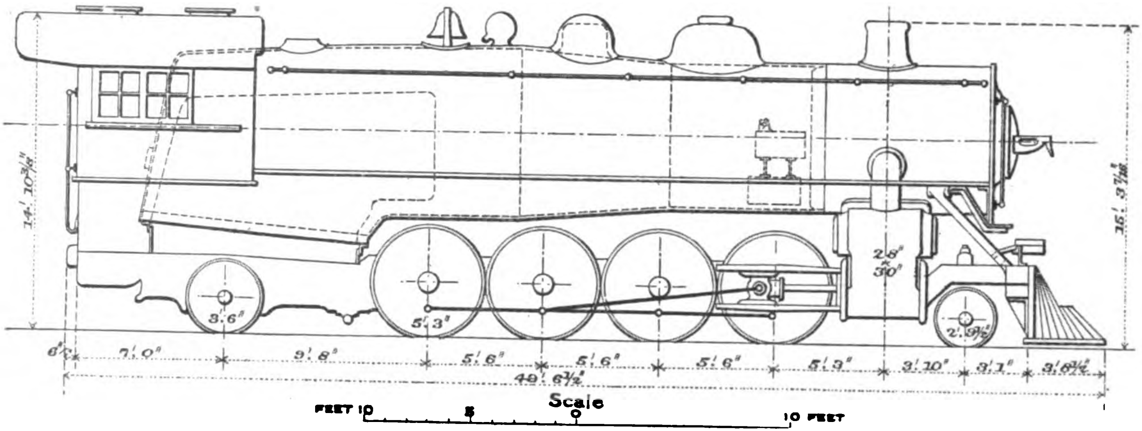
Mr. Bohan.

NORTHERN PACIFIC RAILWAY COMPANY: SUPERHEATER TEST REPORT.

	Average of Four Tests.	Average of Four Tests.
From	Glendive	Dickinson
To	Dickinson	Glendive
Distance, miles	106·2	105·61
Engine	No. 1,736 (*Fig. 32*, p. 102)	No. 1,736 (*Fig. 32*, p. 102)
Cylinder-diameter	28 inches	28 inches
Driving-wheels, diameter	63·98 inches	63·98 inches
Kind of superheater	Schmidt	Schmidt
Number of cars, loaded	42¾	38¼
,, ,, total	46¼	60¼
Weight of cars, loaded	1,747½ tons	1,355 tons
,, ,, total	1,813¾ ,,	1,775 ,,
Number of stops	5½	9½
Schedule running-time	6 hrs. 45 min.	7 hrs. 15 min.
Actual running-time	5 ,, 53¾ ,,	5 ,, 33½ ,,
,, time standing	0 ,, 44½ ,,	1 ,, 27¾ ,,
Total time on road	6 ,, 38¼ ,,	7 ,, 1¼ ,,
Average miles per hour on road	16·00	15·04
,, ,, ,, running	18·01	19·00
,, drawbar pull . . . Lbs.	15,120	14,056
,, ,, horse-power	726·4	712·2
Coal burned, running . . . Lbs.	21,056¼	18,474½
,, ,, standing . . . ,,	255	700
Total coal burned . . . ,,	21,311¼	19,174½
Water evaporated . . . ,,	124,262	110,987
Actual water evaporated per lb. of coal . . . ,,	5·83	5·79
Average feed-water temperature	61¼° F.	64° F.
Equivalent evaporation from and at 212° F.	7·00	6·95
Average steam-pressure . . . Lbs.	179·1	178·8
,, quality of steam moisture . per cent.	1·315	1·42
,, flue-gas temperature at smoke-box	621° F.	618 °F.
,, steam-chest temperature	593° F.	596° F.
,, superheat at steam-chest	214° F.	215° F.
Number of ton-miles	192,615	187,502
Ton-miles per ton of coal, running	18,295	20,299
,, ,, ,, total	18,076	19,557
Coal per 1,000 ton-miles, running . . Lbs.	109·31	98·5
,, ,, ,, total . . . ,,	110·64	102·2
Water per ton-mile, total . . . ,,	0·645	0·591
Coal per drawbar horse-power-hour . . ,,	4·92	4·66
Water ,, ,, . . ,,	29·24	27·00
Temperature	77° F.	76° F.
Number of double strokes 8½ inches cross compound pump	11,985	13,842
Total steam-consumption of pump . . Lbs.	5,396	6,617
Per cent. steam-consumption of pump of total of engine	4·29	5·85

Mr. Bohan.

Fig 32.


14' 10¾"
15' 3⁷⁄₁₆"
28" × 30"
3' 6"
5' 3"
2' 9½"
6"
7' 0"
9' 8"
5' 6"
5' 6"
5' 6"
5' 3"
3' 10"
3' 1"
3' 6½"
49' 6½"
Scale
FEET 10
5
0
10 FEET

NORTHERN PACIFIC RAILWAY: CLASS W3 "MIKADO" GOODS-ENGINE.

Valve-gear	Walschaert.
Grate-area	70·2 square feet.
Superheater	Schmidt.
Total weight of engine	142 tons 17 cwt.
Number of tubes	212 and 40.
Size of tubes.	2¼ inches and 5½ inches.
Heating surface	3,591 square feet.
Superheating surface	838 " "

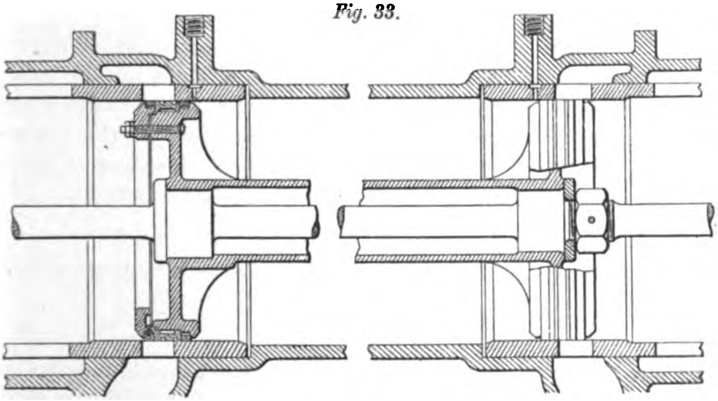
Mr. Dubois.

Mr. Paul Dubois, of Paris, wished to make some observations based on several years' experience with the use of superheating on the locomotives of the Paris–Orleans railway. There were at present on that railway 355 engines fitted with Schmidt superheaters, namely:—

80 four-cylinder compound passenger-locomotives.
85 ,, ,, goods- ,,
125 two-cylinder simple passenger-locomotives.
65 ,, ,, goods- ,,

He considered the damper-doors referred to on p. 82 were useless. Their omission caused no inconvenience from the point of view of maintenance of the tubes: even with the regulator closed and the blower open, the temperature attained entailed no risk of burning the tubes. As their omission was advantageous in other respects, his company were not fitting dampers in new locomotives, and indeed were withdrawing them from engines in service. With regard to air-valves and by-passes, these were employed either alternatively or together. Although the point was not yet quite decided, the use of by-passes alone appeared to give satisfaction. The Schmidt single ring for piston-valves had been superseded by a ring in two parts (*Fig. 33*) which afforded a higher degree of stanchness. For the pistons three rings were usually employed, in place of the two on the ordinary locomotives. The results of trials were substantially the same as those of ordinary running, namely, an economy of 10 per cent. of fuel and 20 per cent. of water, over similar engines not fitted with superheaters. These figures applied equally to the four-cylinder compounds and to the simple-expansion engines. The results varied a little according to the conditions of work, but always ranged round about the figures stated.

Fig. 33.



Mr. Fry. Mr. **Lawford H. Fry** had been particularly interested by the fact that the fuel- and water-consumption tests between London and Leeds had been made with both single-expansion and compound locomotives, the economy obtainable by superheating being determined for both classes. This gave results for four locomotives of generally similar dimensions, differing only in the number of expansions and in the quality of the steam used. To facilitate a comparison of the results obtained, he had compiled the accompanying Table A (p. 177) from the data given by the Author. In drawing up this Table the runs from London to Leeds had been separated from those from Leeds to London, while the coal- and water-consumption per ton-mile in columns 4 and 5 were averaged from the Paper. Columns 6 and 7 showed the coal- and water-consumption of the various engines, expressed as a percentage of that of the single-expansion saturated-steam locomotive, while the last column showed the weights of the locomotives on the same percentage basis. It would be seen that compounding added 3 per cent., and superheating 4 per cent., to the weight of the single-expansion saturated-steam engine, while the combination of compounding and superheating added 5½ per cent. to the weight. The savings shown were :—

Compounding alone	15	per cent. coal and	13	per cent. water.
Superheating „	25	„ „	24	„ „
Compounding and superheating .	37·5	„ „	35	„ „

It appeared from these figures that where superheating, applied to a single-expansion locomotive, would effect a saving of 25 per cent. in coal-consumption, approximately the same percentage of economy could be obtained by its application to a compound locomotive. Similar results had been obtained in France and Germany, and in the former country the majority of superheater engines now provided for the double expansion of the steam, while in Germany, though the combination was more recent, the most modern high-speed passenger-engines were compounds using superheated steam. Another point of interest was the relation between the coal burned and the water evaporated. This was shown in Table B (p. 178), column 3, giving the weight of water evaporated per pound of coal burned, which was found by dividing the water per ton-mile in each test by the coal per ton-mile. The evaporation averaged 8·13 to 9·35 lbs. of water per pound of coal. It was not clear from the Paper whether the water-consumption per ton-mile was based on the actual weight of water or on the equivalent evaporation from and at 212° F. In any case the locomotive-boilers had worked

Mr. Fry.

TABLE A.

	1	2	3	4	5	6	7	8
Test Run.	Locomotive. S.E. = Single-Expansion. C. = Compound.			Consumption: Lbs. per Ton-Mile.		Comparative Figures.		
						Per Ton-Mile.		Weight.
	No.	Class.	Weight.	Coal.	Water.	Coal.	Water.	
			Tons.					
London-Leeds	992	S.E. Sat.	58·2	0·111	0·95	100·0	100·0	100·0
	1,043	C. Sat.	59·9	0·093	0·84	84·0	88·5	103·0
	1,039	"	59·9	0·0915	0·744	82·5	78·3	103·0
	998	S.E. Suph.	60·25	0·086	0·75	77·5	79·0	104·0
	998	"	60·25	0·084	0·72	75·6	75·7	104·0
	1,040	C. Suph.	61·7	0·069	0·645	62·2	68·0	105·5
Leeds-London	992	S.E. Sat.	58·2	0·106	0·93	100·0	100·0	100·0
	1,043	C. Sat.	59·9	0·095	0·87	90·0	93·5	103·0
	1,039	"	59·9	0·919	0·81	87·0	87·0	103·0
	998	S.E. Suph.	60·25	0·076	0·68	71·5	73·0	104·0
	998	"	60·25	0·080	0·71	75·5	76·0	104·0
	1,040	C. Suph.	61·7	0·067	0·594	62·2	64·0	105·5
London-Leeds and return (mean of figures above)	992	S.E. Sat.	58·2	0·109	0·94	100·0	100·0	100·0
	1,043 1,039	C. Sat.	59·9	0·0928	0·823	85·0	87·0	103·0
	998?	S.E. Suph.	60·25	0·082	0·715	75·0	76·0	104·0
	1,010	C. Suph.	61·7	0·679	0·619	62·5	65·0	105·5
Toton-Brent	3,815	S.E. Sat.	45·15	0·164	1·337	100·0	100·0	100·0
	3,835	S.E. Suph.	49·1	0·115	0·882	86·0	80·0	109·0
Brent-Toton	3,835	S.E. Sat.	45·15	0·0785	0·729	100·0	100·0	100·0
	3,815	S.E. Suph.	49·1	0·0673	0·579	82·0	75·0	109·0

Mr. Fry.

TABLE B.

Test Run.	1	2	3	4	5	6	7
	Locomotive. S.E. = Single-Expansion. C. = Compound.		Water evaporated per Pound of Coal.	Ton-Miles.	Total Coal burned during Test.	Running-Time.	Coal burned per Sq. Ft. of Grate per Hour of Running Time.
	No.	Class.	Lbs.		Lbs.	Hours.	Lbs.
London-Leeds	992	S.E. Sat.	8·55	55,954	6,700	4·00	59·0
	1,043	C. Sat.	9·03	60,000	5,590	4·00	49·2
	1,039	”	8·13	63,100	5,770	4·10	49·6
	998	S.E. Suph.	8·72	57,100	4,920	4·00	43·3
	998	”	8·57	57,160	4,800	4·00	42·3
	1,010	C. Suph.	9·35	63,500	4,390	4·10	37·6
Leeds-London	992	S.E. Sat.	8·75	58,870	6,220	3·75	59·0
	1,043	C. Sat.	9·15	60,550	5,750	3·75	54·0
	1,039	”	8·82	65,400	6,000	3·75	56·4
	998	S.E. Suph.	8·95	58,850	4,480	3·75	42·0
	998	”	8·90	60.500	4,850	3·75	45·5
	1,010	C. Suph.	8·85	68,660	4,600	3·75	43·2
Toton-Brent	3,815	S.E. Sat.	9·27	90,788	7,130	7·75	43·5
	3,835	S.E. Suph.	8·60	89,526	5,180	7·75	31·7
Brent-Toton	3,815	S.E. Sat.	7·92	72,700	9,000	4·66	91·5
	3,835	S.E. Suph.	7·27	72,644	7,350	4·66	74·8

with a high degree of efficiency. At first sight it appeared remarkable that the highest evaporation per pound of coal was obtained with the superheater. In *Fig. 34*, which had been prepared to explain this, the weights of water evaporated per pound of coal (Column 3) had been plotted as ordinates, over the rates of firing in pounds of coal per square foot of grate per hour (Column 7) as abscissas. The rates of firing had been obtained by multiplying the ton-miles (Column 4, Table B) by the coal per ton-mile (Column 4, Table A), thus obtaining the figures for total coal fired, which were given in Column 5, Table B. These figures, divided by the running-time obtained from the Appendix and by the grate-area, gave the coal fired per square foot of grate per hour, as in Column 7. *Fig. 34* showed clearly that the evaporation per pound of coal diminished as the rate of firing was increased, and that the high evaporations in the superheater tests were due to economy in water-consumption, which enabled the same work to be done with a smaller coal-consumption and a consequently lower rate of combustion. The points plotted for the London–Leeds tests fell fairly well into two groups, one for the superheated-steam, and the other for the saturated-steam tests, and through each group a fairly representative line had been drawn. Four points from the Toton–Brent tests had also been plotted. Those for saturated steam fell

Mr. Fry.

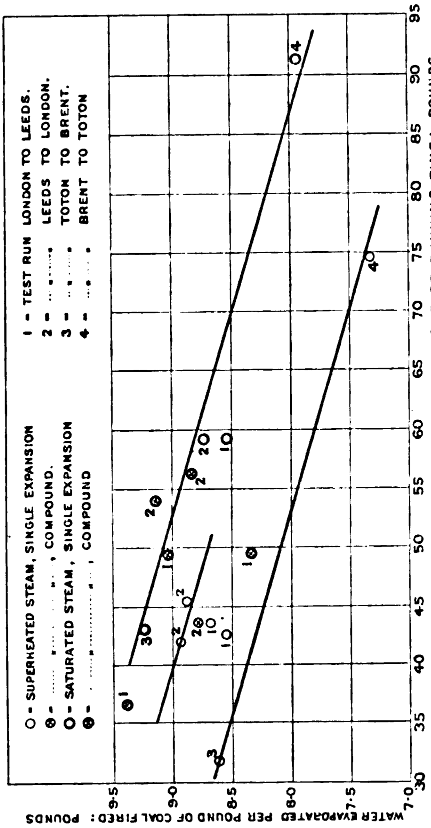


Fig. 34.

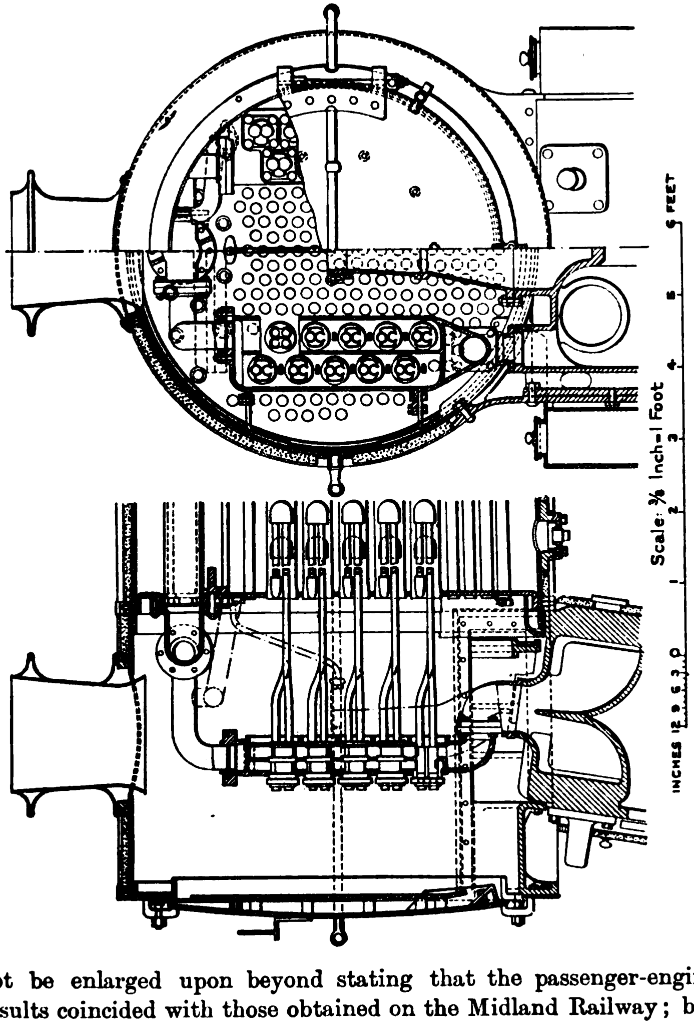
Mr. Fry. close to the London–Leeds results, but those for superheated steam showed a considerably lower evaporation per pound of coal than was obtained between London and Leeds. The indicator-diagrams given by the Author were very interesting, but it was not clear why there was such a large drop between boiler- and steam-chest pressure for the saturated steam. This was particularly noticeable in Figs. 20, Plate 2, where the drop between boiler and steam-chest was much larger for the saturated than for the superheated steam. The reverse had been found to be the case in the Pennsylvania Railroad tests to which the Author referred. In these American tests—and the same thing had been observed elsewhere—the resistance of the superheater was more than sufficient to offset the increased fluidity of the steam in its passage from the boiler to the steam-chest; and the consequent drop in pressure had been found to be considerably greater than that in a saturated-steam locomotive. It seemed probable that in the Author's experiments the regulator of the saturated-steam locomotive was not fully open when the diagrams in Figs. 20 were taken.

Mr. Goss. Professor W. F. M. Goss, of the University of Illinois, U.S.A., considered that the Paper constituted an important contribution to technical literature. The Author emphasized the advantage of superheating steam as a means of improving the efficiency of the steam-locomotive. Equal emphasis might well be given to the fact that any device which promoted efficiency in steam-locomotive service might be employed as a means of increasing the maximum output of power. A superheater locomotive which was required to perform the same service as that performed by a saturated-steam locomotive would, as had been so well shown by the Author, perform that service on a smaller expenditure of fuel. It was equally true, and, from the standpoint of American railway practice, even more important, that such a locomotive, when supplied with a given quantity of fuel, would run faster or pull heavier trains than a saturated-steam locomotive fired with the same quantity of fuel. The fact that superheating served to extend the limit of power in service where the coal-consumption had already reached the maximum, was a significant factor in the sum total of benefits to be derived from the practice of superheating.

Mr. Hughes. Mr. GEORGE HUGHES considered that in regard to the broad subject-matter of the Paper there was very little to discuss, the successful application of superheating to locomotives in England and in other countries being a matter of common knowledge. Consequently, a Paper on the subject might be divided into two

Mr. Hughes.

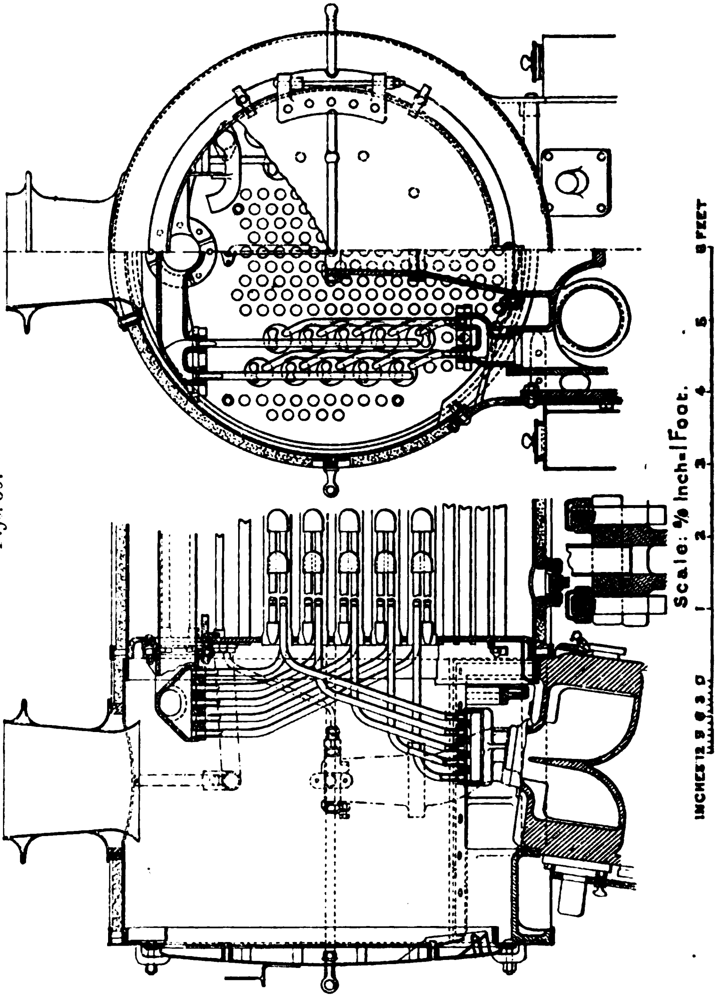
parts, one recording the system adopted and the results obtained, and the other dealing with certain details of construction peculiar to superheating, as well as details which might be common to every locomotive, such as by-pass and relief valves. The work done on the Lancashire and Yorkshire Railway was well known and need



Figs. 35.

not be enlarged upon beyond stating that the passenger-engine results coincided with those obtained on the Midland Railway; but in the former case 73 per cent. of the superheater engines employed were goods- and mineral-engines, and here again the results practically coincided with the Author's. *Figs. 35–40* illustrated the

Mr. Hughes. Horwich superheater, with which thirty-eight engines were fitted. The results obtained were equivalent to those of the Schmidt design. This must be the case with any designs having equal superheating surfaces; the rest was simply a question of details, cost of manufacture, and adaptability for ease of management in the sheds. With regard to constructional details, possibly the Author was a little doubtful about the use of dampers, because he said: "The ends of the elements which are nearest the fire-box may be rapidly



Figs. 35.

Mr. Hughes.

burnt." If so, Mr. Hughes entirely agreed; the matter was uncertain, and dampers were used only as a precautionary measure. On the Lancashire and Yorkshire Railway about fifty engines were running without dampers. Some had done so for about 12 months, which was not long enough to enable a definite pronouncement to be made, and consequently he left this detail for the moment with an open mind. *Figs. 12*, showing the results of the use of by-pass

Figs. 37.

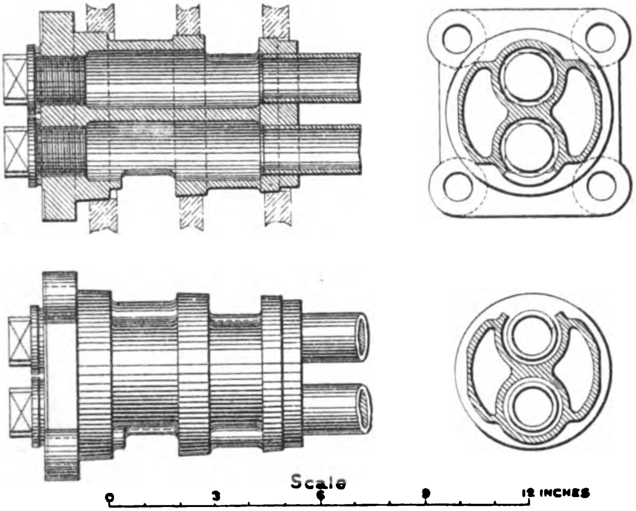
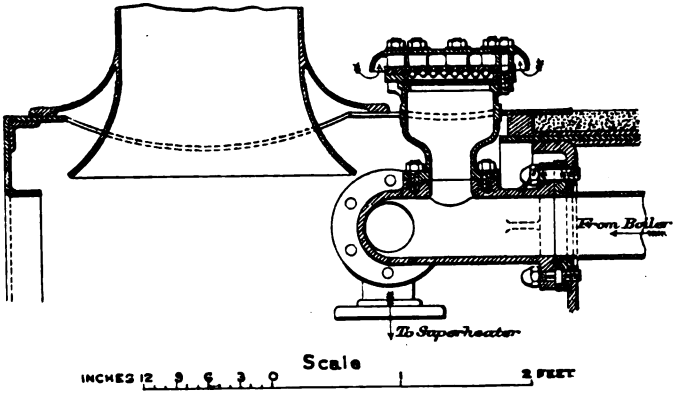
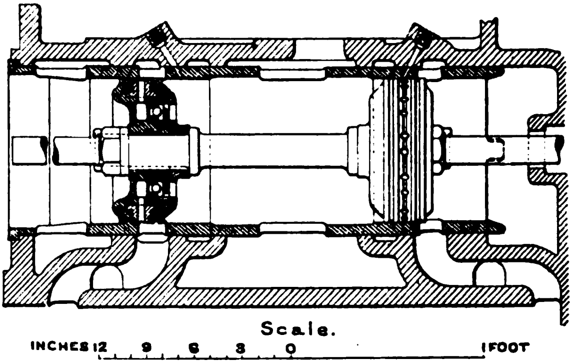

Scale
0
3
6
9
12 INCHES

Fig. 38.


From Boiler
To Superheater
Scale
INCHES 12
9
6
3
0
1
2 FEET

Mr. Hughes. and air-valves, were in general accord with the Lancashire and Yorkshire Railway practice, but Mr. Hughes was inclined to attach a higher value to the air-valve than the Author put upon it, as fully demonstrated by *Fig. 40*, which was another way of showing what the Author had given in diagram form on p. 84 ; but *Fig. 40* showed a clear gain for the air-valve. Possibly the Author might conclude that his air-valves were not large enough, being only 3½ square inches, as compared with that shown in *Fig. 38*, which had 9·6 square inches; and even that was not sufficient. As to the value of relief-valves, most of the pressure-relief valves fitted to locomotives in England and on the Continent dissipated the back pressure into the atmosphere, which, of course, was a distinct loss, and Mr. Hughes had devised a form of automatic relief-valve, which he had applied not only to piston-valves, but also to slide-valves in considerable numbers. The main feature of this valve was that its application was absolutely automatic whatever the back pressure might be on the piston, or whatever the steam-chest pressure; whereas those generally fitted had a predetermined pressure, and consequently were automatic only for and above that pressure. This automatic relief-valve discharged the back pressure into the steam-chest, and consequently had an economical value, which was found to be equivalent to 4 per cent. of the coal-consumption. Enlarging upon the value of air-valves and by-pass valves, their objects might be stated to be threefold, namely:—

Fig. 39.



(A) To reduce the engine resistance.

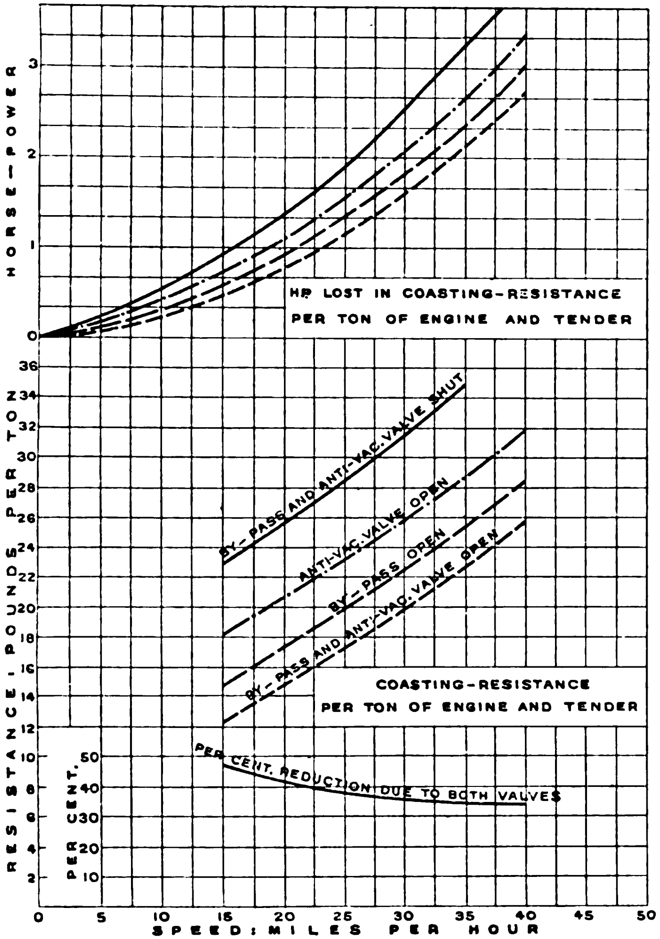
(B) To reduce the suction of smoke-box gases into the cylinders.

(C) To circulate air through the superheater.

Mr. Hughes.

(A) The reduction of engine-resistance was of much more importance in an express passenger-engine than in a goods-engine. The Lancashire and Yorkshire Railway experiments showed that at a speed of 60 miles per hour the total coasting-resistance of an express engine and ten coaches could be reduced from about 3 tons to 2½ tons by suitable anti-vacuum arrangements. This 16 per cent. reduction was of considerable value, as full advantage could be taken of free running. It was practically the same as was found by plani-

Fig. 40.



Mr. Hughes. metering the Author's diagrams. At lower speeds, say 30 miles per hour, the reduction was much more marked. *Fig. 40* showed the results of experiments made upon an engine with 20-inch cylinders, 26 inches stroke, and 61-inch wheels, coasting from rest on a gradient of 1 in 82. The by-pass had a net area of 5·03 square inches, and the anti-vacuum valve 9·6 square inches. At a speed of 25 miles per hour there was the following reduction of engine-resistance (coasting):—

(1) 29 per cent. due to the by-pass.
(2) 18 per cent. due to the anti-vacuum valve.
(3) 38 per cent. due to by-pass and anti-vacuum valve together.

This did not, of course, affect the running-resistance, which would be represented approximately by the lowest line on the diagram, because when under steam the pumping action would be absent. In the case of goods-engines, where free running was frequently accompanied by the necessity of braking, the advantage of a reduction in the coasting-resistance was not so marked, as it was usually effective in assisting the brakes and keeping the cylinders warm.

(B) His experience had led him to the conclusion that the presence of large quantities of deposit in the cylinders and steam-passages was due to the suction of smoke-box gases by the piston, which was more pronounced in engines not provided with a by-pass. Chemical examination of the deposit showed that it consisted of 32 to 78 per cent. of oxides of iron, small quantities of calcium and magnesium compounds, and also largely of substances of vegetable origin, which, as they could only come from the fuel, could not be attributed to the oil.

(C) Steam-chest temperatures were taken with a Foster pyrometer whilst coasting, under the following conditions:—

By-pass	Shut	Open	Shut	Open	..
Anti-vacuum valve	Shut	Shut	Open	Open	..
	°F.	°F.	°F.	°F.	
Steam-chest temperatures, °F., in coasting from rest to 35 miles per hour . . .	400 to 455	410 to 430	510 to 530	490 to 500	First test.
	..	390 to 400	500 to 530	500 to 510	Second test.
Mean rise	55	15	25	10	..

This showed the by-pass valves to be the more effective in keeping down the temperature, and the combined effect with the anti-vacuum valve was more marked still. With regard to the use of

Mr. Hughes.

tail-rods, experience on the Lancashire and Yorkshire Railway had shown that the piston-rings began to wear as soon as the tail-rod bushes had worn, and the Midland Company's method of lubrication ought to be very effective in reducing the wear of the bushes, and so indirectly of the piston-rings. The Lancashire and Yorkshire Railway Company had carried out some investigations in regard to the holding power of tubes. Experiments made upon steel tubes, 3¾ inches in diameter, showed that by far the best practice was to expand them into the plate and bead them over. The holding strength when merely expanded was 14 tons, while when expanded and beaded over it was 36 tons. There did not appear to be any additional advantage in turning ribs on the tubes as well as beading over the ends. The different methods of securing the tubes showed greater strength, as compared with the plain tube merely expanded, to the following extent:—

	Increase in Strength. Per Cent.
1. Ribbed tube, 3¾ inches in diameter, expanded in copper tube-plate	39
2. Plain tube, 3¾ inches in diameter, expanded in copper plate and beaded over	157
3. Ribbed tube, 3¾ inches in diameter, expanded in copper plate and beaded over	156

The present practice on the Lancashire and Yorkshire Railway was to bead over the flue-tubes in the fire-box tube-plate, and simply to expand them without beading over in the smoke-box tube-plate. The question of lubrication was a very important one. The lubricant used on the Lancashire and Yorkshire Railway contained 6 per cent. of fixed oil, and the viscosity was slightly greater than that of the Author's oil: the flash-point was about 600° F., and Mr. Hughes exercised great care in the use of mechanical lubricators delivering the oil as near as possible to the spot where it was required. He agreed generally with the Author's statements about maintenance. Having dealt with the matter elsewhere,[1] he would simply state that twenty Schmidt superheater goods-engines, 0–6–0 type, had been running in competition with an equal number of non-superheater engines of the same type, the mileage of the former to the 31st August, 1912, being 867,514 and for the latter 744,454 miles. The ton-mileage was 332,208,505 and 270,940,977 respectively, and the total coal-consumption 63,974,731 lbs. and 63,397,584 lbs.,

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[1] "Compounding and Superheating in Horwich Locomotives," Proc. Inst. Mech. E., 1910, p. 399.

Mr. Hughes. showing economies of 13·4 per cent. per train-mile, and 18·3 per cent. per ton-mile respectively. The ratio between the train-mileage and the engine-mileage was 64·2 per cent. for superheater engines and 59·4 per cent. for saturated-steam engines. One hundred and ten superheater locomotives were now in service on the Lancashire and Yorkshire Railway, namely, twenty-six passenger- and eighty-four goods-engines.

Mr. Hume. Mr. E. S. **Hume**, of Midland Junction, Western Australia, remarked that the question of using superheated steam in locomotives had received consideration in Western Australia for some time past, and it had been discussed at the annual conferences of officers of the several State railways of Australia. The adverse conditions under which the Government railways were worked in Western Australia—the imported fuel being high-priced and the local fuel hydrous and semi-bituminous—together with the bad quality of the only water available at many points, rendered any amelioration by reduction of boiler-pressure, saving in coal- and water-

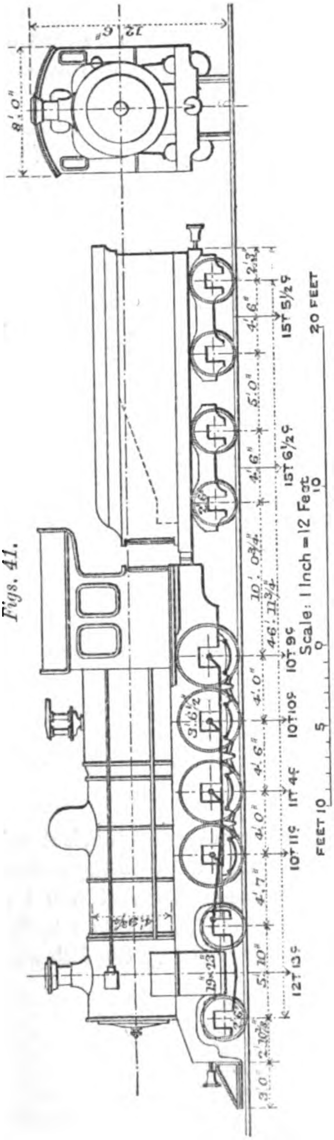
PARTICULARS OF LOCOMOTIVES, CLASSES "FS" AND "F."

TYPE 4-8-0. EIGHT-WHEEL TENDER.

Item.	"Fs" Superheated. (*Figs. 41*, p. 117.)	"F" Saturated.
Boiler:		
Type	Belpaire	Belpaire
Grate-area	18·8 sq. ft.	18·8 sq. ft.
Heating-surface:		
Fire-box	125 ,,	126 ,,
Tubes	977 ,,	1,235 ,,
Superheater	261 ,,	..
Total	1,363 ,,	1,361 ,,
Working-pressure	160 lbs. per sq. in.	175 lbs. per sq. in.
Cylinders:		
Number	2	2
Diameter by stroke	19 ins. by 23 ins.	17 ins. by 23 ins.
Diameter of piston-valve	8 ins.	8 ins.
Motion:		
Type	Walschaert	Walschaert
Outside lap	⅞ in.	⅞ in.
Inside negative lap	Nil.	Nil.
Wheels:		
Coupled, diameter	3 ft. 6½ ins.	3 ft. 6½ ins.
Bogie ,,	2 ,, 6 ,,	2 ,, 6 ,,
Tender ,,	2 ,, 6 ,,	2 ,, 6 ,,
Weight in working order:		
On coupled wheels	42 tons 14 cwt.	42 tons 9 cwt.
,, engine	55 ,, 7 ,,	54 ,, 2 ,,
,, engine and tender	85 ,, 19 ,,	84 ,, 14 ,,

consumption, and in cost of boiler-repairs, peculiarly desirable. It was therefore decided that a trial of the Schmidt system of superheating should be made on goods-locomotives. Of twelve "F" class locomotives constructed by the North British Locomotive Company, Glasgow, two were fitted with Schmidt superheater. These two had been designated "Fs" to distinguish them. They were illustrated in *Figs. 41* and particulars of them were given in the Table on p. 188. These locomotives were put into service in November, 1912, but no definite trial was made for some months, to allow time for initial troubles to be overcome and for the enginemen to become familiar with the working of the superheaters. In the beginning, valve-packing gave some trouble, the piston-valves being arranged for outside steam-admission. The original composition of the packing was advised as being lead 80 per cent., antimony 20 per cent. Analysis of this metal after it had failed in use gave lead 88·45 per cent., antimony 11·5 per cent., undetermined 0·05 per cent.; and the melting-point was found to be 481° F. After experimenting with metallic packing of various compositions, a trial was made with

Mr. Hume.



Figs. 41.

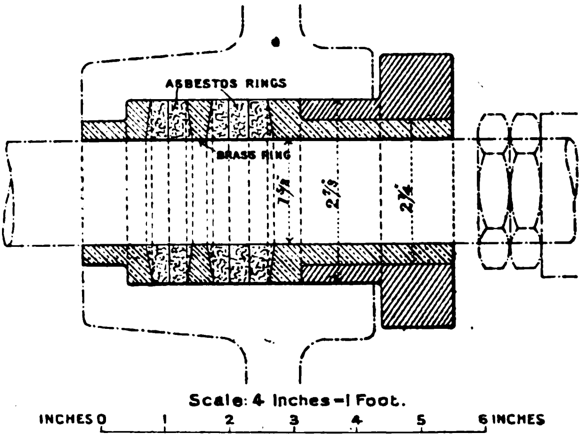
West Australian Government Railways: Class "Fs" (Superheater) Locomotive.

Heating-surface, Tubes . .	977 sq. ft.	Boiler-pressure	160 lbs. per sq. in.
" " Fire-box .	125 "	Tractive-power (max. M.E.P. in cylinder = 75 per cent. of boiler-pressure) . . .	23,445 lbs.
" " Superheater	261 "		
Grate-area	18·8 "		

Total weight in working order . . . 85 tons 19 cwt.

Mr. Hume. asbestos rings, as illustrated in *Fig. 42*. This proved satisfactory, and the valve-spindle glands were now fitted with that type of packing. The wear on this comparatively soft material, however, was such that it could not yet be stated that asbestos had been finally adopted. The piston- and valve-rings in use were shown in *Figs. 43* and *44*. The results obtained were very fair. Trouble was experienced with steam-pipe flanges, which were screwed and brazed. It was found that the brazing metal did not run regularly into the cavity, and a better result was obtained by having the pipe properly screwed into the flange without brazing. The oil used on the superheater locomotives had a flash-point of about 600° F., and its viscosity by a standard Redwood instrument was 1·146 second at 140° F. and 286½ seconds at 200° F. The oil was applied by a Wakefield eight-feed mechanical lubricator delivering to the cylinder-barrel, to the piston-valve, and to the piston tail-rod. The quantity of cylinder- and valve-oil allowed was 1 pint per 100 miles. The nature of the boiler feed-water taken by these engines at the time of trial was shown generally by the following data :—

Fig. 42.

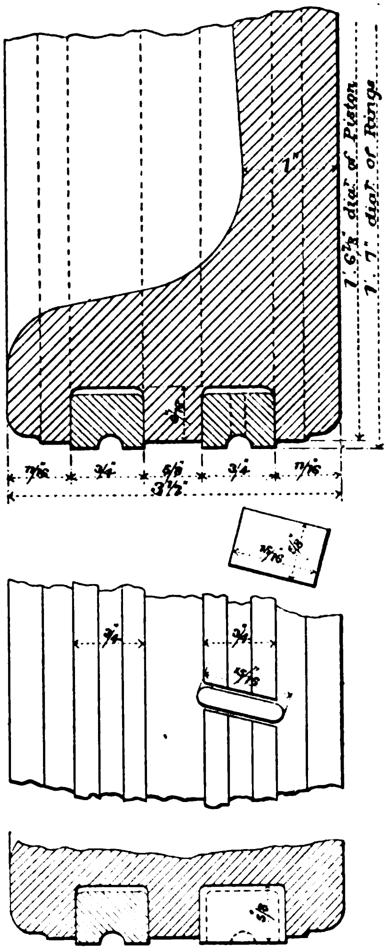


	Grains per Gallon.
Alkaline chlorides	20·47
Magnesium chloride	5·31
Calcium sulphate	1·63
,, carbonate	0·55
Iron oxide and alumina	0·14
Silica	0·42
Total solids	28·52
Total hardness	7·27
Temporary hardness	0·55

Mr. Hume.

Before entering the boiler the water was treated by adding 11 oz. of carbonate of soda per 1,000 gallons, to neutralize its corrosive properties. On account of the nature of West Australian feed-waters, the following particulars of the boiler might be of interest:—The barrel, the wrapper plates, the smoke-box tube-plate, the back plate, and the stays were of mild steel; the fire-box was of copper; the boiler-tubes (other than superheater tubes) were of brass of 70/30 composition; and the large tubes for superheater elements were of copper. The tubes were cleaned with a steam spiral tube-cleaner, the steam-valve for operating this being placed on top of the boiler about 1 foot from the smoke-box tube-plate. Tests of coal-consumption were arranged between one "F" class locomotive having a saturated-steam boiler, and one "Fs" engine having a superheated-steam boiler. The methods of testing were practically those described on p. 93. The same engine-men were employed on each engine, the weather conditions were equal, and the locomotives were not overloaded. Details of the results of the tests were given in the Tables on p. 193. Summarizing them, it would be seen that the superheater engine saved 35 per cent. in fuel and 38 per cent. in water, as compared with the non-superheater engine. Further, it would be noted that the "Fs" boiler carried only 160 lbs.

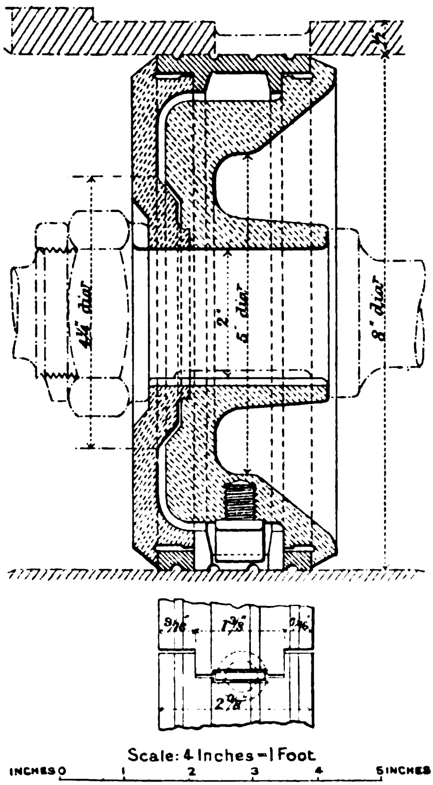
Figs. 43.



Scale: Half Size.

Mr. Hume. per square inch pressure, while the "F" boiler was pressed to 175 lbs. The coal used was obtained from Newcastle, N.S.W., and was of the following quality:—Calorific value, 13,298 B.Th.U. per pound; ash, 10·02 per cent.; moisture, 1·34 per cent. The local coal cost at the mine 11*s.* per ton, and had the following general quality:—Calorific value, 10,500 B.Th.U. per pound; ash, 6·5 per cent.; moisture, 20 per cent. New South Wales imported coal cost *ex* ship 20*s.* 9*d.* per ton, the average quality being: calorific value, 13,805 B.Th.U.; ash, 8·35 per cent.; moisture, 2·7 per cent. It was found that the superheater engine would haul with ease a load which would require a great effort on the part of the saturated-steam class. The time-table speed over these heavy gradients with the goods-trains worked was 15 miles per hour, exclusive of stops. In addition to the two "Fs" locomotives, seven Garratt locomotives recently imported from Great Britain had been fitted with the Schmidt superheater, but these engines had not been in service long enough to justify a statement as to their work beyond saying that there was a marked reduction in coal- and water-consumption. The water used in the district where these Garratt engines worked cost 5*s.* 6*d.* to 8*s.* per 1,000 gallons, and it was practically the same as that to which the analysis already given related. As experience with superheater engines so far had been altogether satisfactory, it was intended at a convenient opportunity to try the system on other classes of main-line locomotives, with balanced D valves, as

Figs. 44.



Mr. Hume

WESTERN AUSTRALIAN GOVERNMENT RAILWAYS: TEST OF SUPERHEATER AND ORDINARY ENGINES.
Fuel: Newcastle Coal.

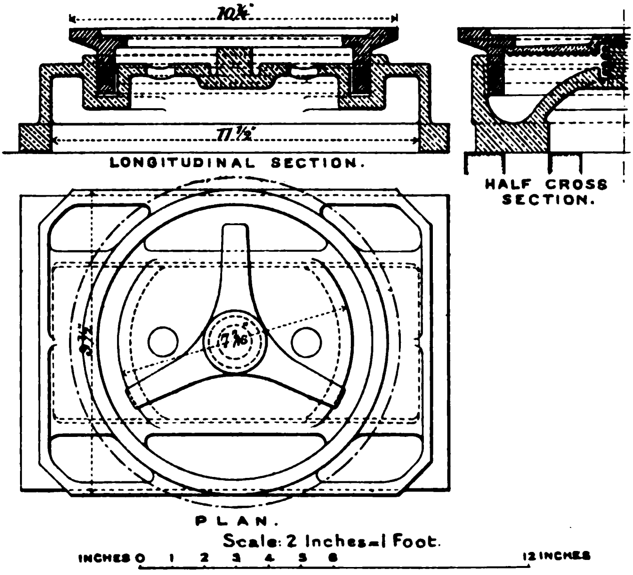
Engine No.	Dates of Running.	Days Run.	Coal Used.	Water Used.	Miles Run.	Coal Used per Mile.	Water Used per Mile.	Ton-miles Hauled.	Coal Used per Ton-mile.	Water Used per Ton-mile.	Steam Temperature. Maximum.	Steam Temperature. Average.	Average Steam-Pressure.
			Lbs.	Lbs.		Lbs.	Lbs.		Lb.	Lb.	°F.	°F.	Lbs. per Sq. In.
					SUPERHEATER ENGINE, CLASS "FS."								
366	26/2/13	1	5,917	40,250	81	73·0	496	22,913	0·258	1·75	610	580	150
,,	27/2/13	1	6,148	42,750	81	75·9	527	24,538	0·250	1·73	620	580	150
,,	28/2/13	1	5,995	42,730	81	74·1	527	23,170	0·258	1·84	600	570	150
,,	3/3/13	1	5,056	33,000	81	62·4	407	19,161	0·263	1·72	610	580	150
		Averages				71·3	490	..	0·257	1·76	..	577	150
					SATURATED-STEAM ENGINE, CLASS "F."								
362	7/3/13	1	8,253	55,500	81	101·0	685	21,521	0·383	2·57	..	..	155
,,	10/3/13	1	7,421	59,500	81	91·0	734	18,001	0·412	3·30	..	..	155
,,	11/3/13	1	8,536	56,500	81	105·0	697	21,479	0·397	2·63	..	..	155
,,	12/3/13	1	7,912	58,000	81	97·0	716	19,672	0·402	2·94	..	..	155
		Averages				99·0	708	..	0·398	2·84	..	..	155

NOTE.—Weight of engine is not included in figures "Ton-miles hauled."

Mr. Hume. shown in *Fig. 45.* The advantages of the superheater "Fs" engines over the saturated "F" class might be summarized thus:—

(1) They would haul the full load of a saturated-steam locomotive of similar design with comparative ease.
(2) No blowing-down or scumming of the boiler was necessary.
(3) There were no leaky tubes or stays.
(4) The working-costs (covering all maintenance-charges) were in their favour, but the engines had not been long enough in service to establish a definite comparison.

Figs. 45.



(5) The conditions for the engine-men in passing through tunnels were better, due to drier exhaust steam and easier handling of the train.

Mr. Jackson. Mr. H. H. **Jackson**, of Wellington, N.Z., observed that on the New Zealand Government railways only a few locomotives had been fitted with superheaters, mostly on the Schmidt system, which up to the present had given satisfaction. Slight trouble had been experienced with leakage in large tubes, and some of these had lately been welded to the tube-plate and were standing well. Lubrication gave slight trouble owing to the high degree of superheat, namely, 650° F., and the fact that the best quality of lubricant was not used for the purpose. A saving of about 18 per cent. in coal and 22 per cent. in water per train-mile had been effected on engines working heavy goods-trains. So far no passenger-engines had been equipped; all the modern passenger-engines were now four-cylinder compounds. Mr. Jackson.

Mr. CHARLES R. KING stated that he had studied for some time past numerous documents on the subject of superheater locomotives, and was of opinion that the data given by the Author, although not comparable with the elaborate dynamometer tests carried out on continental railways, confirmed the fact that with superheated steam there were deficiencies in power-development, which, however, were not always admitted. He reviewed the superheating practice on English railways between 1830 and 1870, and pointed out that British engineers had thus paved the way for the revival which began in 1900. Between 1850 and 1860 they achieved success, notwithstanding the defective lubricating-oils then available. He referred to the success obtained by Mr. J. E. McConnell, Locomotive Superintendent of the London and North-Western Railway, and also to remarks made at the Institution in 1860,[1] in reference to Great Western Railway locomotives fitted with superheaters in 1845. The saving of coal then realized equalled, if it did not exceed, that now claimed, and a fuel-economy exceeding 20 per cent. was obtained with moderate superheat[2]; high superheat appeared to be impossible with the lubricating-oils then available. The superheaters then used were practically identical with those of to-day, being built of straight pipes, jointed with union caps or U bends, and bolted to headers; and in support of this statement he cited various patents, such as those of Allchin, de Montcheuil, and Montety. By about 1870 every possible form of superheater for locomotives had been patented, and the older and best patents had then become public property. With regard to the Author's statement that with the use of superheated steam the boiler could be worked at a lower pressure, or, if the same pressure were maintained it could do the same work without being so hardly pushed, Mr. King had not found a single record of a result which was not precisely the reverse. The documented figures published by the Italian State Railways, and the Paris-Lyons-Mediterranean Railway, showed that, whatever might be the power of any superheater locomotive, that same locomotive, when adapted Mr King.

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[1] Minutes of Proceedings Inst. C.E., vol. xix, p. 480.

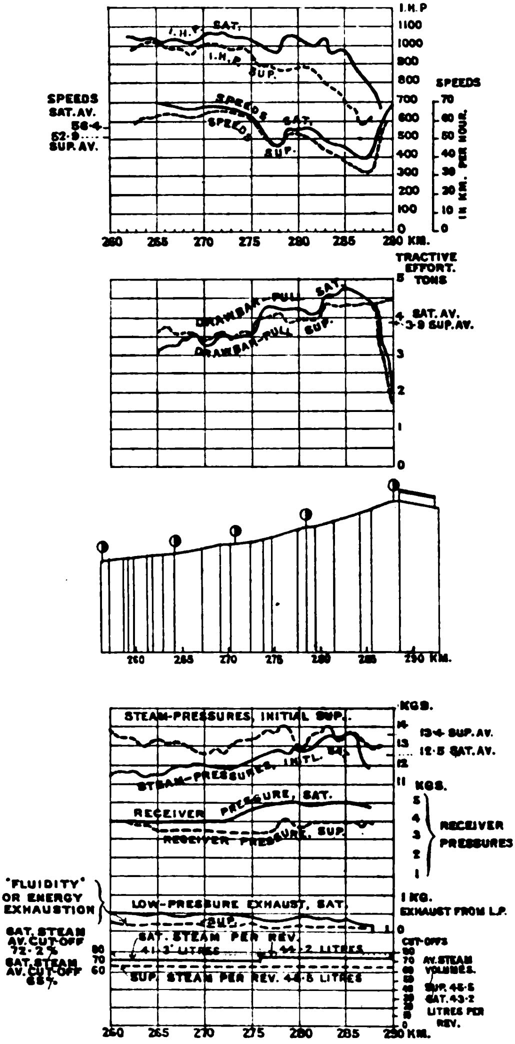
[2] *The Engineer*, vol. ii (1861), p. 200.

Mr. King to use saturated steam, was always 15 to 25 per cent. more powerful than the superheater engine. The natural consequence of using superheated steam was a coal-economy of 3, 7, or even 10 per cent. in regular service—as compared with the purely exhibition figures of 27 to 28 per cent.; but at the same time there was lower power, lower speeds, smaller loads, and considerably greater engine-weight per unit of work. *Figs. 46* showed that superheated steam, even when working with a pressure 6·7 per cent. higher, and using 6 per cent. more steam (by volume) was, nevertheless, incapable of obtaining the same speed as the saturated-steam engine, the average speed being 6·2 per cent. lower, while the draw-bar pull was 3 per cent. less. These Figures also showed a train-load of 461·8 tons with saturated steam, and of 453·5 tons with superheated steam. Moreover, 15 per cent. higher pressure was needed with superheated steam in order to develop the same mean pressure in the cylinders. The average indicated power for the entire trip from La Roche to Dijon was 911 I.HP. for the saturated engine and 875 I.HP. for the superheater engine. In its more efficient service the saturated-steam engine burned 1,224 kilograms of coal, instead of only 1,044 with the superheater, and it also used 25 per cent. less oil, of an inferior quality, per mile. It could also be deduced from the Figure that each unit of saturated steam produced 21 per cent. more work than superheated steam on the gradient shown. Although the superheater engine generally weighed about 3 tons more, owing to the addition of the superheater, and the heavier cylinders also added still further to the weight, the dead weight in this particular case had been specially reduced to make the superheater locomotives only 1 ton heavier, equivalent to 1·4 per cent. additional weight. The useful weight hauled behind the tender, per ton weight of the loaded engine, was 6·53 tons with saturated steam and 6·32 tons with superheated steam, and each engine was driven to the full limits of its power. For a superheated-steam locomotive to accomplish the same work in the same time as the saturated-steam locomotive, he found from the records that the initial pressure must be increased by 12 to 18 per cent. In order to avoid this alternative it had been usual and obligatory to increase the volume of the cylinders—or otherwise to introduce more steam at each stroke—the object being to compensate the low heat-content of the superheated steam per cubic foot, by a volume about 20 per cent. larger, in order to bring up the total heat to that contained in saturated steam of 20 per cent. lower pressure, or 20 per cent. smaller volume. By superheating steam to 250° F., at 213 lbs. per square inch absolute in the valve-

Mr. King.

chest, the internal energy per cubic foot was reduced by about 22 per cent., and the mechanical work developed at the draw-bar usually averaged 18 per cent. less, resulting in 18 per cent. lower speed. This was not at all a question of individual engines, whether locomotive, stationary, or marine, but a fundamental question of the efficiency of the substance carrying the heat. Many locomotive-engineers agreed that superheat was really a feeble form of steam-power, but claimed to have triumphed over the difficulty by using 20 per cent. larger cylinders, or 20 per cent. longer cut-offs. The fact which each engineer had to remember was that those enlarged locomotives for superheated steam would develop 20 per cent. more power if worked with saturated steam at the same pressure. More than this, the same weight of boiler as was used for superheated steam would more easily supply saturated steam to fill those enlarged cylinders. Many engineers made the mistake of

Figs. 46.



Mr. King. supposing that because the specific volume of superheated steam was 27 to 34 per cent. greater than that of dense moist steam at the same pressure, it followed naturally that this larger volume would be generated in the same time as an equal volume of saturated steam in saturated-steam locomotive-boilers weighing 2 to 3 tons less. They claimed that 27 to 34 per cent. more steam was produced by reason of this dilatation, but they also claimed a water-economy of 15 to 22 per cent.: which contradicted the first claim, and really proved that the evaporative capacity of the superheated-steam boiler had really been reduced by this amount through the loss of water-heating surfaces entailed by the addition of the superheater. However much the coal might be piled on the fire-box the superheater boiler could not be made to evaporate beyond a certain given limit, and the reason why the lighter-boilered saturated-steam locomotives during dynamometer tests always hauled the heaviest loads, attained the highest average speed, and were unexcelled for climbing steep gradients, was that the boiler was not forced. He gave an example of this in the following Table of evaporative tests of two locomotives, fitted with the same superheater as that recommended by the Author, in competitive service on railways:—

	Saturated Steam.	Superheated Steam.
Steam-pressure, absolute average initial . .	213 lbs.	213 lbs.
Weight of the same boiler without and with Schmidt superheater and accessories . .	20 tons	23·6 tons
Weight of above apparatus	..	3·6 ,,
Water-evaporation per hour, average . . .	19,743 lbs.	17,600 lbs.
Reduction in the rate of evaporation per hour	..	10 per cent.
Average superheat	..	200° F.
Steam-production per hour	39,880 cub. ft.	47,341 cub. ft.
Increased percentage of dilated steam . . .	..	15·7 per cent.
Total internal energy per hour . . B.Th.U.	22,013,760	21,068,080
Reduction in energy per hour	..	4 per cent.
Reduction in energy per ton weight of boiler.	..	18 ,,
Cubic feet of steam per ton of boiler per hour	1,994	2,014[1]
Greater production of dilated steam per hour	..	1 per cent. nearly

It would be seen that the fuel-economy realized during these test trips agreed with those given by the Author; and the results given Mr. King. below confirmed the fact that the Author's figures were quite normal:—

---

[1] In service with these engines 16 to 20 per cent. more steam was used to develop 1 HP.

TEST-TRIP ECONOMIES WITH SUPERHEATING AND WITH DIFFERENT RATIOS OF CYLINDER-VOLUMES: COAL PER TON-MILE, INCLUDING ENGINE.

	Simple Expansion.	Compound.	Economy.
			Per Cent.
Superheated steam.			
Midland Railway	a 0·80	b 0·0679	$b : a = 15$
Italian State Railway . . .	..	c 0·0593	$c : b = 12$
Saturated steam.			
Midland Railway	..	d 0·0916	$b : d = 25$
Italian State Railway . . .	..	e 0·0795	$c : e = 25$ $c : d = 13$

The greater coal-economy of 12 to 13 per cent. in the Italian compound engine was to be attributed to the better steam-economy resulting from a cylinder-ratio of 1 : 2·68, instead of 1 : 2·4. Between test results and working results, however, it was always found that there was a diminution of 10 to 20 per cent. in the economy, as was exemplified by the following figures:—

	Coal-Consumption per 100 Kilometres run and per Ton, including Engine and Tender.
	Kilograms.
Superheater (Schmidt) locomotive, new boiler	2·67
Saturated-steam locomotives without superheater (entire group)	2·77
Saturated-steam locomotive No. 6878	2·66
„ „ „ No. 6867	2·67

The regular saving per year with the superheater locomotives (which under test conditions showed 25 per cent. economy) was 3·5 per cent. over the saturated-steam locomotives in good order. The Midland Railway tests were remarkable as showing a very considerable water-economy per ton-mile, but if reckoned on the horse-power-hour basis, and taken over a considerable time, the water-economy would be 5 to 7 per cent. less. Although there was not a

Mr. King. single indication in the Paper of the average cut-off employed, or of the working-pressures (initial or mean effective), he assumed, from incidental references, that the working superheat was 250° F. and the valve-chest pressure about 205 lbs. per square inch, with a boiler-pressure of 220 lbs., from which he deduced the following figures:—

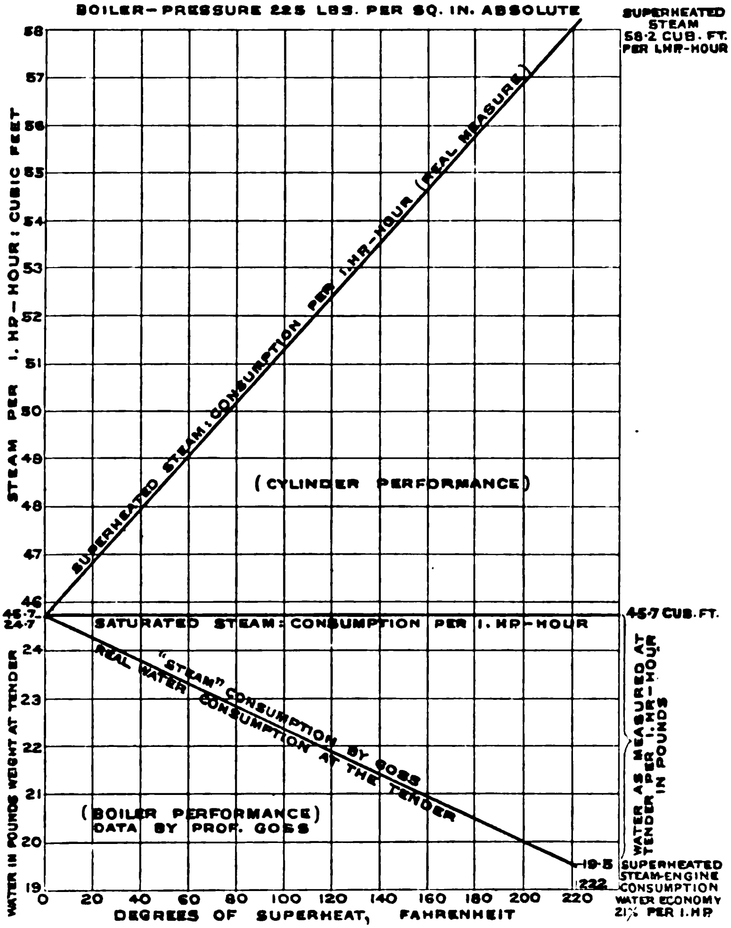
MIDLAND RAILWAY SUPERHEATED-STEAM AND SATURATED-STEAM COMPOUNDS.

—	Superheated.	Saturated.
Water per ton-mile at the tender	0·619 lb.	0·797 lb.
,, ,, in the cylinders . . .	0·910 ,,	0·797 ,,
Steam ,, ,, ,, . . .	1·81 cubic foot	1·58 cubic foot

From this it appeared that the steam-consumption in the cylinders when using saturated steam would be 1·81 − 1·58 ÷ 1·81 = 12 per cent. less. The difference of 12 per cent. was small, but in this case the basis was ton-mileage, which left out the factor of speed, which, from his observations, was always greatest with saturated-steam locomotives.

He then compared tests of engines made in Saxony in 1848 with locomotives indicating 250 HP., where the volume per revolution was 3 85 cubic feet and the boiler-pressure 78 lbs. per square inch, which gave 0·83 HP. per unit of P*v*. This was compared with the tests made with a superheated-steam engine in 1912, indicating 1,600 HP., in which the volume per revolution at 50 per cent. admission was 12·9 cubic feet, and the boiler-pressure 170·5 lbs. per square inch, which gave 0·72 HP. per unit P*v*, thus showing that the saturated steam had a higher efficiency, per unit of P*v*, by 13 per cent. He also pointed out that, while the tests made on the Paris-Lyons-Mediterranean Railway showed a coal-economy of 17 per cent. in favour of superheating, the annual economy per ton-mile was 7 per cent. On Swiss railways this economy appeared to be 6 per cent. The reason why the annual coal-economy was so moderate was that it was dependent upon many conditions affecting the working of the boiler, which conditions were continually varying. Steam engineers and professors of steam engineering stated the steam-consumption in the cylinder in pounds weight per hour of the water-consumption as measured at the tank, both for saturated and for superheated steam, and were thus able to claim for superheating a saving of steam of 20 to 30 per cent. of the total steam used, said to be due to "elimination of condensation" in the cylinder. They also reasoned that the superheater engine was able to develop 20 to 30 per cent. more power, or work with a steam-pressure 20 to 30 per cent. less, and could still save 20 to 30 Mr. King.

Fig. 47.



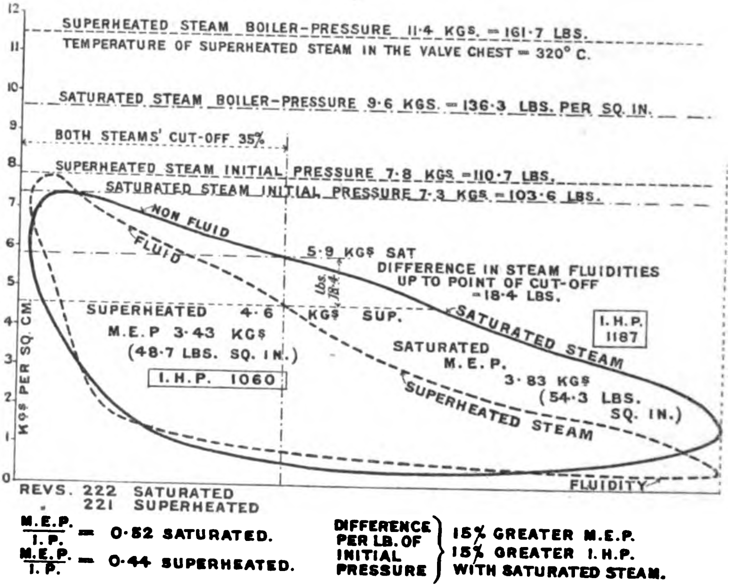
per cent. of the coal. This, he protested, was the greatest and most obvious illusion in the annals of steam engineering. The Author gave figures which corresponded generally with those obtained by Professor Goss at the Purdue University, and Mr. King

Mr. King. therefore showed, in *Fig. 47*, the steam-consumption taken from one of Professor Goss's tests, to which he had added the steam-consumption per indicated horse-power-hour, "real measure." This addition to the diagram was now published for the first time, the graph being unknown to steam engineers. It would be seen that there was a water-saving of 21 per cent. per indicated horse-power-hour in favour of the superheater engine, which Professor Goss termed a saving in steam-consumption, totally ignoring the change of state in the steam, which weighed 0·540 lb. per cubic foot when dry saturated, and 0·334 lb. when superheated to 222° F., in both cases at the absolute pressure of 255 lbs. per square inch. Thus the consumption of the saturated-steam engine was 45·7 cubic feet per indicated horse-power-hour, and of the superheated-steam engine 58·2 cubic feet, or 21 per cent. more. By terming water "steam," the real state of matters was reversed, and it could then be claimed that 21 per cent. less steam was consumed as the result of superheating. Saturated-steam locomotives could haul the heaviest loads and attain the highest speeds upon the most difficult parts of the line, and this appeared to be due to the fact that although the pressure plus volume admitted with superheated steam was 20 per cent. greater than that allowed to the saturated-steam locomotives, yet the determining factor in the superheater locomotive was the evaporative capacity, which was always much lower at its maximum than in saturated-steam locomotives. This was now being recognized, as was proved, for example, in the design of the new engines of the London and South Western Railway Company. As showing to what extent saturated steam was capable of hauling greater loads per ton weight of engine, and at higher speeds, with the same boiler-pressure as superheated steam, the competitive tests of the Paris, Lyons and Mediterranean Railway were especially instructive, because the engines (using both qualities of steam) were made to work a very difficult line rising a net height of 1,050 feet in a distance of 83 miles when hauling trains as heavy as those now worked by the more recent type of "Pacific" compound locomotives. In a number of dynamometer tests with regular trains (eight in all) the average coach-load with the superheater engines was 380 tons and the average indicated power 871 I.HP.; with the saturated-steam engines the corresponding figures were 417 tons and 910 I.HP. The superheater engines, fully loaded, weighed 71·7 tons and hauled 5·3 tons per ton of locomotive; the saturated-steam engines, weighing 70·7 tons, hauled 5·9 tons per ton of locomotive, or 10 per cent. more than the superheaters. The salient fact in all the dynamometer tests in

France, Italy, Bavaria and elsewhere, was that, although superheater locomotives often ran faster down inclines, and sometimes also on the level, the aggregate work recorded by the dynamometer was 5 to 6 per cent. less with superheated steam than with saturated steam. On rising gradients, however, the steeper the gradient became, the more the power and the speed of the saturated-steam locomotive rose above those of the superheater locomotive, even though the latter might have 15 per cent. larger cylinders and weigh 1 to 3 tons more. The Author's suggestion that superheated steam was more fluid than saturated steam, and thereby produced more power in the cylinder, appeared to be far more remarkable than anything else in his Paper. Every one acquainted with the peculiar properties of superheated steam would admit that there was a certain possibility of greater fluidity in a fluid which never ceased to shrink in volume and temperature from the instant that it passed the last bend in the superheater on its way to the cylinders. On the other hand, saturated steam maintained its volume and pressure under cold; thus the condensed water or moisture formed a steam of super density, of the temperature and pressure of the steam with which it was in contact, falling again to its specific density on entering the cylinder. If indicator-cards from modern high-pressure superheater locomotives, having very carefully jacketed cylinders, were compared with cards taken from non-jacketed cylinders of the same size using saturated steam of only one-third the initial superheated-steam pressure, it would be found that not only did the wet saturated steam develop up to 25 per cent. more power, but also the fall of pressure between the valve-chest and the cylinder was greater than with saturated steam. *Fig. 48* gave an example, and showed that on entering the cylinder the fall of temperature was more rapid, entailing a more rapid fall of pressure up to the time that the valve closed in the case of the superheated steam, as compared with the non-fluid saturated steam. The latter, by virtue of its higher density, carried a reservoir of latent pressure with it. The diagram for the superheated-steam engine had been taken from a modern new engine having the cylinders inside the frame and asbestos-clothed. In the case of the saturated-steam engine the cylinders were outside, were not "lagged," but had steel casing. They were old engines of obsolete type. In the case of the superheated-steam engine, the mean effective pressure was 48·7 lbs. per square inch and the power 1,060 I.HP. In the case of the saturated-steam engine the mean effective pressure was 54·3 lbs. and the power 1,187 I.HP.; the number of revolutions per minute was Mr. King.

Mr. King. 221 and 222 respectively. The difference in the steam fluidities up to the point of cut-off was 18·4 lbs. per square inch, as shown in the Figure. The diagrams given by the Author to show what he claimed as greater fluidity of the superheated steam, because at the beginning of the stroke there was considerably higher pressure than in the saturated-steam engine, were precisely the reverse of any indicated diagram that Mr. King had ever seen, including those by Professor Goss. In all diagrams that he had seen the low initial pressure (indicated by dotted lines in the Author's diagrams) would be from superheated steam, and the high initial pressures (shown by solid lines) from saturated steam. On the other hand, the reduced back pressure with superheated steam was universally remarked. The smoke-box vacuum often fell, in consequence, below the requirements of the draught, and two remedies were employed, either chimneys of smaller sectional area, or smaller openings to the blast-nozzles. The lower back pressure was simply due to exhaustion of the expansive power of the superheated steam. The theory of "greater

Fig. 48.



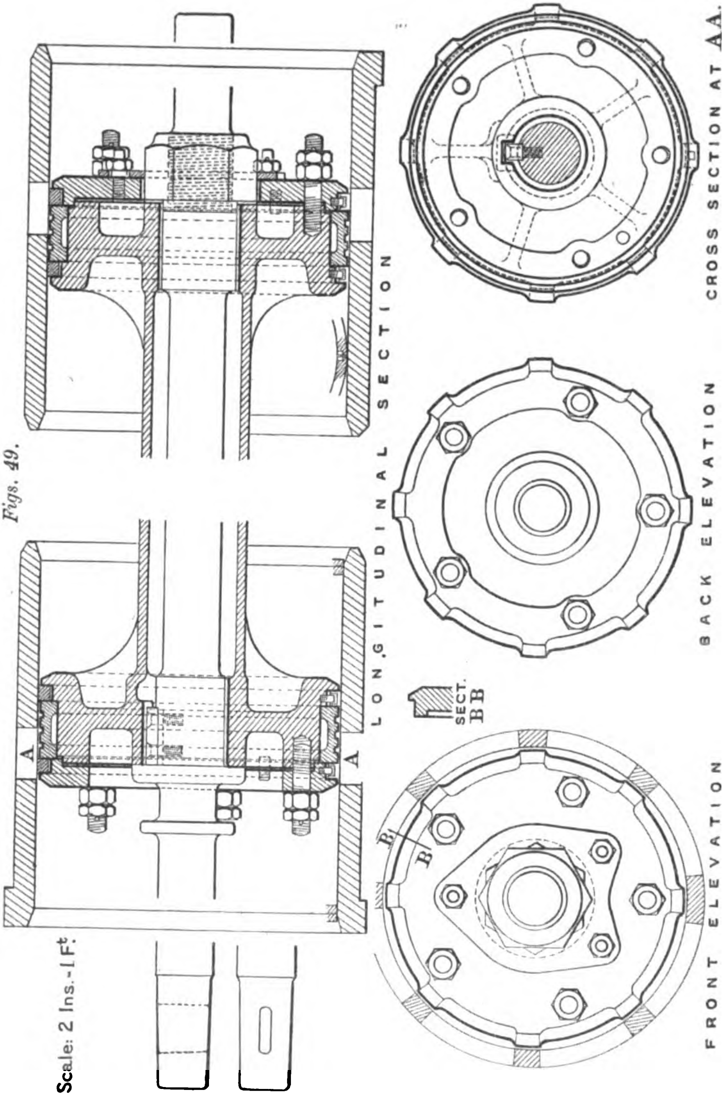
Typical Indicator-Diagrams Characteristic of Superheated and Saturated Steam Expansions.

Mr. King. fluidity" was a double-edged argument. It enabled the claim to be made that with a cut-off of 50 per cent. as much superheated steam could be introduced into the cylinder per second as of saturated steam at 60 per cent. cut-off. That, however, was only when the draughtsman had calculated the duty of the boiler on the supposition that, for a given cut-off for different qualities of steam, each would consume the same volume of steam per hour; but it would be found that, having omitted to calculate this "fluidity," the superheated-steam engine really consumed $\frac{60-50}{60}$, or 16 per cent. more steam per horse-power-hour than the saturated-steam engine. Mr. King concluded by urging the employment, during future locomotive tests, of steam-flow meters such as were used in power-houses to measure the steam delivered to the engine, instead of measuring the water-consumption of the boiler: these would definitely and immediately show that, on a given steam-consumption, saturated steam would perform equal work on a reduced pressure by 18 per cent. or equal work on a reduced steam-delivery by 18 per cent.

Mr. Lucy. Mr. E. E. LUCY, of Redfern, N.S.W., stated that on the New South Wales Government railways locomotives fitted with Schmidt superheaters had given excellent results in regard to economy of both fuel and water, whilst providing greater hauling-power. A further 278 superheater engines were now being constructed or arranged for.

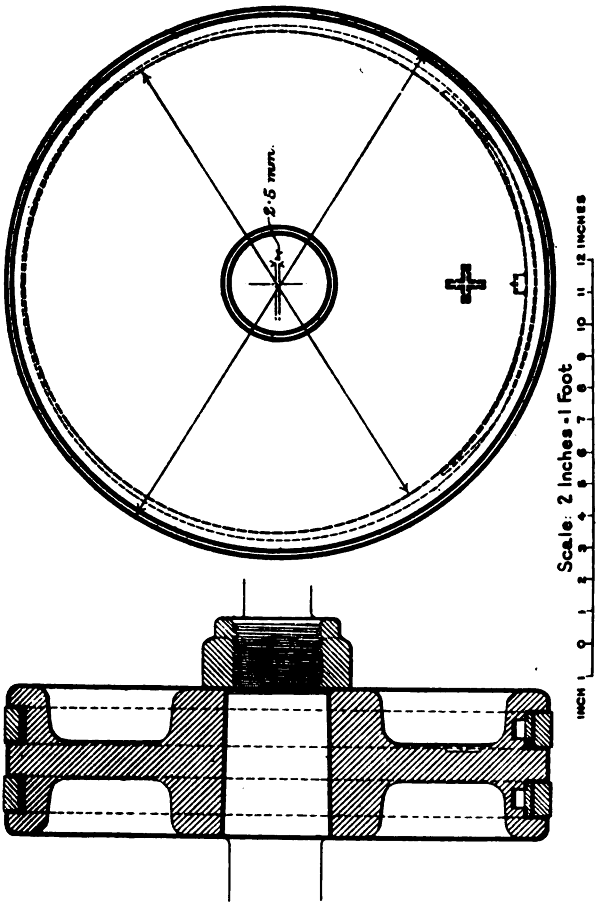
Mr. Maréchal. Mr. L. MARÉCHAL, of Paris, observed that on the Paris-Lyons-Mediterranean Railway the dampers formerly fitted to all types of superheater locomotives had been removed, and none would be provided in future. They formed a cumbersome and heavy accessory, of little importance from the point of view of maintenance of the superheater-tubes. Experience had shown that while the Schmidt piston-valve with a wide split-ring was more effective than the solid Garbe type, it was still markedly inferior to the valve employed for a considerable time past in the P.-L.-M. saturated-steam locomotives, which alone was now fitted (*Figs. 49*). Further, the Schmidt steam-piston with three rings had been abandoned in favour of the Company's earlier type, having two rings, each 30 millimetres wide, with spring centering (*Figs. 50*). After a fairly extended comparative experience, thermo-electric pyrometers had been definitely adopted. They were of the Siemens-Halske type, modified in accordance with the Company's instructions.

Mr. Maréchal.


LONGITUDINAL SECTION
CROSS SECTION AT AA.
BACK ELEVATION
FRONT ELEVATION
SECT. BB
A
A
B
B
Scale: 2 Ins.-1 Ft.

Figs. 49.

Mr. Maréchal.



Figs. 50.

Mr. Nadal.

Mr. Nadal, of Paris, observed that experience on the French State railways confirmed the majority of the results obtained by the Author. The employment of superheaters had become current practice; many advantages had been found, and a considerable number of the State locomotives were now fitted with them. With regard to fuel-economy, he had not had occasion to compare, from this point of view, similar simple locomotives, with and without superheat, because the modern locomotive stock of the State railways consisted entirely of four-cylinder compound engines. These, however, when fitted with superheaters, showed in running an economy ranging from 10 to 15 per cent. as compared with engines not so fitted. Latterly, simple locomotives with superheated steam

Mr. Nadal. had been employed. So far as could be judged hitherto, their fuel-consumption was not less than that of the four-cylinder compound saturated-steam locomotives fitted with flat slide-valves, and he considered that the slide-valve—flat or cylindrical—played an important part in the matter of fuel-consumption.

Mr. Peckitt. Mr. R. G. PECKITT considered that the all-round efficiency of a locomotive was much enhanced by the use of superheated steam, and he was also of opinion that it was desirable to get the highest degree of superheat permissible with the present means of lubrication. For this reason he had recommended the fitting of the Schmidt superheater on the last batch of locomotives ordered by the Administration of the Egyptian State Railways, namely, five passenger-engines and ten goods-engines—five of which had yet to be delivered. The five goods-engines had been in service for about 2 months. They were undoubtedly superior, in hauling-power and in economy of coal and water, to a very similar type, using saturated steam, that had preceded them. Both of these classes of locomotives were constructed by Messrs. Henschel and Son, of Cassel, Germany. The five passenger-engines were just being put into service. These had been made by the Berliner Company, of Schwartz-Kopff, Berlin, and so far only one had been taken into regular express service. After its erection in Egypt this locomotive made two trips on local service and was then passed straight to express work; and on its third trip, on a day of about the roughest weather experienced in that country, it was the only one that worked a Cairo–Alexandria express to time. The engine was worked at 20 per cent. cut-off with the regulator fully open, and the temperature of the steam, as shown by the pyrometer, was 600° F., the oil used having a flash-point of about 560° F. The normal load of these trains was ten bogie coaches, totalling, all told, about 380 tons; the road was level and unprotected from wind, and the booked speed, 49·7 miles per hour, did not include stops, which, in the case of most of these expresses, were five in a distance of 130 miles. The engine was a 4–4–2 "Atlantic" type, with outside cylinders and Walschaert motion. The other engines working similar expresses on this date were 4–6–0 simple and 4–4–2 De Glehn compounds, both types using saturated steam. The weight of the new 4–4–2 "Atlantic" engine was 73 tons, that of the 4–6–0 simple 70 tons, and that of the 4–4–2 De Glehn compound 67 tons. In the superheater engines he had increased the cylinder-diameter from 19 inches to 20 inches—provision having been made in the thickness of the walls for boring out to 20½ inches, in addition to the usual allowance for wear. He regretted that, owing to the short time these engines had been in service, he was unable to furnish any results; but he was so satisfied with what he had seen of them that he intended to have the next locomotives ordered fitted with superheaters giving a high degree of superheat. Mr. Peckitt.

Mr. W. W. Pickersgill, of Inverurie, considered that the indicator-diagrams were very interesting. He was unable, however, to reconcile the diagrams in Figs. 19 and 20, Plate 2. Diagram No. 3, Fig. 20, showed expansion-curves for both saturated and superheated steam. The mean effective pressure of the saturated-steam curves was approximately 15·19 per cent. of the boiler-pressure and the superheated-steam curve was 24·85 per cent., or more than half as much again; and as the miles run per hour were practically the same, the indicated horse-power in the case of the superheater engine would be more than 50 per cent. more than that of the ordinary engine when running at 55 miles per hour. The chief advantage claimed by the Author for the superheaters was their economy, but these diagrams showed a considerable increase in the power of the engine. The two diagrams shown in Figs. 19, Plate 2, when the engine was running at 56·6 and 56·3 miles per hour, for saturated and for superheated steam respectively, did not show the same difference in the mean effective pressure. Had the Author found much difference in the tractive force of engines built exactly alike, and using saturated and superheated steam respectively, when running at speeds ranging from 40 to 60 miles per hour with similar boiler-pressure and cut-off, and, if so, could he give the results of his experiments? Mr. Pickersgill.

Dr. Wilhelm Schmidt, of Cassel, considered that the Paper dealt with the subject in a very able and complete manner. The Author had recognized that it was essential to use gases of a high temperature in order to obtain an efficient superheater. With the smoke-tube type of superheater it was necessary to subdivide the stream of fire-gases emerging from the fire-box into two portions, one passing through the ordinary boiler-tubes and the other portion through the large flues which contained the superheater-pipes. The ratio of the volume of fire-gases passing through the large flues to the volume of fire-gases passing through the ordinary boiler-tubes would be a principal factor in determining the degree of superheat that would be developed. The larger this ratio, the higher would be the degree of superheat. Assuming the fire-gases to be drawn through all the boiler-tubes with the same velocity, or, in other words, that the draught of the gases was evenly distributed over the whole cross section of the boiler, the above-mentioned ratio would be expressed by the ratio of the total cross section of the fire- Dr. Schmidt.

Dr. Schmidt. gas stream in the large flues to the total inner cross section of all the ordinary boiler-tubes. Evidently it was necessary to determine the diameter of the large flues and the small superheater pipes in a certain fixed relation to the size of the ordinary boiler-tubes. If, for instance, the large flues were of too small a diameter or the superheater pipes were too large, the degree of superheat would be reduced; the gases would in such case prefer to pass through the ordinary boiler-tubes where they would have a comparatively easy passage and would neglect the superheater part of the boiler. On the other hand, it followed that if certain sizes of large flue and superheater pipe were correct in a boiler with 1¾-inch tubes, the same sizes of flues and superheater pipes would not be as efficient in the same boiler equipped with 2-inch tubes. It was not sufficient, however, to subdivide the gas-stream in the correct proportion; it was also essential for the efficiency of the superheater to expose to the gases passing through the large flues the proper amount of superheating surface in order to use effectively the heat of the gases. Owing to the low conductivity of superheated steam it was necessary to expose to each cubic foot of gases passing through the superheater-flues 20 to 30 per cent. more heating-surface than was exposed to each cubic foot of gases passing through the ordinary boiler-tubes. It was therefore necessary to keep the diameter of the ordinary boiler-tubes, the large superheater-flues, and the small superheater-pipes in a certain relation to each other, in order to fulfil the foregoing requirements; and he believed that a large part of the success of his smoke-tube superheater must be attributed to the fact that he had recognized these requirements from the beginning and had selected the right proportions of tube-diameters—which were still used in his superheater and had also been adopted by other designers. The Author mentioned that experiments made on the Pennsylvania Railroad showed that the temperature in the large flues was 100–200° F. higher than in the ordinary boiler-tubes. These conditions were caused, as stated, by the larger volume of fire-gases passing through the flue; and in this connection the following consideration might be of interest. The cooling effect of the evaporative heating-surface of the boiler-tubes was inversely proportional to the diameter of the tube. If d denoted the inside diameter of the tube, $d^2\pi/4$ would be a measure of the volume of gases passing through this tube and $d\pi$ a measure of the heating-surface by which the gases passing through the tube transmitted their heat to the surrounding water. $\frac{d\pi}{\frac{d^2\pi}{4}} = \frac{4}{d}$ would therefore be a factor indicating the heat-transmission, or, in other words, the cooling effect of the boiler-water on the gases. This factor was inversely proportional to the diameter of the tube. The larger the diameter of the tube, the higher would be the temperature of the gases at a certain distance from the fire-box. The diameter of the large flues in a superheater boiler was more than twice that of the ordinary boiler-tubes; the gases entering the large flue would therefore undergo only one-half the cooling effect through the surrounding water that they would undergo for the same distance from the tube-sheet in the ordinary boiler-tubes. This condition would exist until the gases in the large flues met the return bends of the superheater-pipes, which were usually situated about 2 feet from the fire-box tube-sheet. For the very reason that the fire-gases met the return bends of the superheater-pipes with such a high temperature, it was necessary to protect those pipes by means of dampers or similar devices while no steam was flowing through them. If, however, a superheater were designed in which the superheater-flues had an inside diameter of only about 2½ inches, that was, about one-half the size of the standard design, then before the gases entering the superheater-flues met the return bends of the superheater-pipes they would already be so effectively cooled by the surrounding water that dampers could be dispensed with. In such designs only two superheater-pipes were placed in each flue, instead of the four used in the standard smoke-tube superheater. This type of superheater, with small superheater-flues and only two pipes in each flue, was already used to a considerable extent on the Continent, and was particularly advantageous in shunting-engines and for similar services which necessitated frequent stopping, because the dampers could be dispensed with and a higher degree of average superheat could be obtained. Dr. Schmidt.

Mr. A. E. Seaton considered that the Paper was very interesting and contained some startling statements, notwithstanding the fact that the locomotive was not, prima facie, a good instrument for making the most of superheated steam. That the potential energy of a pound of superheated steam was greater than that of a *pound* of saturated steam of the same pressure was obvious, but that its efficiency was higher required experimental demonstration. In the early days of superheaters the working-pressure on board ship did not exceed 45 lbs. per square inch absolute; steam as produced in the marine boiler had a temperature of 525° F. and was generally wet—sometimes very wet, so that the internal parts of the engine were partially waterlogged, and so clogged as to reduce both the mechanical and the thermal efficiency. The ratio of expansion in Mr. Seaton.

Mr. Seaton. the ordinary marine engine then employed was only two at full speed, and never more than four or five when cruising or making long voyages, and it was all effected in one cylinder, which was exposed to the temperature of the condenser for a considerable portion of the stroke, while the steam when superheated entered at 572° F. The most important function of the superheater in those days was to dry the steam and to give it such an amount of superheat as to prevent dew-deposit until after expansion had commenced in the cylinder. The heat for this purpose was derived from the gases in the uptake, which otherwise would have been wasted, so that such gain as resulted entailed no special expenditure of fuel. But in ample well-proportioned boilers with only natural draught and good stoking, the temperature in the uptake was seldom higher than 450° F., and often less than 400°, so that the possible amount of superheat was necessarily small; consequently the temperature in the main steam-pipe was only 300° to 350°; in fact, 400° F., possible when the boilers were forced, was considered much too high and dangerous. The cylinder-lubricant was generally tallow, the boiling-point of which was 660° F. and which flashed at 540° F., so that there was really little danger inside the cylinder, but the lagging was of felt, which might have fired at higher temperatures. The economy and the good working of the engines supplied with superheated steam was marked, so that had not the higher pressures come into fashion with the compound engine, every ship would have had a superheater, in spite of the fact that the tubes wore out rather quickly, and that ferrules like those introduced by Vice-Admiral Sir Henry Oram, M. Inst. C.E., 20 years ago, had to be fitted to the tube-ends at the entry part of the superheater.

A marine engine, unlike a locomotive, was generally required to run at an even consumption of steam, as well as a regular speed of revolution; consequently, the temperature in the uptake was fairly constant, and always considerably in excess of that of the steam produced in the boilers. It would therefore be always more or less superheated by heat otherwise wasted; even 50° F. of superheat was a distinct advantage, notwithstanding the opinion held by some engineers that only very considerable superheat could effect a material saving on shipboard. The locomotive had to run at varying speed, and with a demand for steam always varying, sometimes largely; there might be times, therefore, when the temperature in the smoke-box, and even in portions of the tubes, was not high enough to produce appreciable superheat. Also, since there was only one boiler, the temperature could not at times be maintained high enough—as could be done on shipboard and in

Mr. Seaton.

an electric generating-station—by cutting out some of the boiler-units instead of closing the dampers of the whole battery engaged. With varying loads a separately fired or controlled superheater was very desirable to get the best results from an engine, as the amount of superheat then was not only uniform but also might be as high as circumstances would permit. In England, with ordinary double-acting engines and turbines, a temperature of 550° F. to 600° F. was as high as prudence dictated; in Scandinavia and in other parts of Europe engines were worked with steam as high in temperature as 700° F., but only special engines would do so with safety. The large tube from the fire-box to the smoke-box, with the superheating tubes within it, constituted virtually an independently-fired apparatus, and should give quite good superheat, even when the fires were checked. Some years ago, when the demand for higher pressure for triple-expansion engines was made, and 200 lbs. per square inch became the fashion with electrical engineers, who were bent on reducing their fuel-bill as low as possible, he had ventured to suggest that they might attain the same economy by a moderate amount of superheating of the steam at 150 lbs. pressure. In order to demonstrate this, he had a Belliss-Morcom triple-expansion engine tried at the 200 lbs. gauge-pressure for which it was made, and the steam-consumption, power, etc., carefully noted, as could be easily done in the test-house of that firm; subsequently it was tried again, running at the same speed and with the same load, but with steam of 150 lbs. gauge-pressure superheated to 388° F., which was the temperature of saturated steam at 200 lbs. per square inch, or 215 lbs. absolute pressure. Although the addition in temperature was in this case only 22° F., the steam-consumption per brake horse-power-hour was less than when working with the 200-lb. saturated steam. As a matter of fact, the capacity, for doing external work, of 1 lb. of saturated steam at 215 lbs. per square inch absolute pressure was 337·5 B.Th.U. (778 foot-lbs.), while that of 1 lb. of steam at 165 lbs. pressure superheated to 388° F. was 336 B.Th.U.; the gain in this case was therefore due to mechanical rather than to thermal causes—in other words, the engine was more efficient with the superheated steam. In everyday work, especially when the engine's internal parts had in course of time worn somewhat, the difference would undoubtedly be more in favour of the lower pressure, as leakage would then become a more serious factor. He must confess that he did not like the employment of steel tubes bent to so sharp a curve as that shown, either for efficiency or for long service. He had had no personal experience with them, but considered, from what he had known to occur elsewhere with sharply-

Mr. Seaton. bent tubes, that the metal would corrode more quickly than in the plain part, and that there would be corrosion inside. He might be mistaken; if so, the evidence of those who had used such tubes would demonstrate this. The locomotive had no exposed long steam-pipe as was common on shipboard and in central stations; its cylinders were usually in a warm place, and, altogether, the necessity for high initial superheat did not exist; the expansion of the steam took place in one cylinder only, instead of in three or four, with the consequent pipes and passages; and finally, the steam passed into the air, and not into the condenser, so that the locomotive-engineer was not concerned with any questions of vacuum, quantity of cooling-water, etc. It might be observed, however, that the same engine, when working with a considerable amount of superheat, caused a rise in vacuum above what was the case when running at the same load, etc., using the same quantity of cooling-water, with saturated steam of the same pressure. The working of the engine, even when drawing an express train, was very intermittent, while the opportunities and facilities for accurate observation were generally small, and always less than was the case with the marine engine. Even with the latter, the methods of observation and record were not good compared with those provided and used in the test-houses of the manufacturers of modern central-station machinery. The Author would therefore forgive him when he expressed surprise, mingled with doubt, at the great gains shown in some, if not in all, of the experimental runs, the results of which had been recorded. The following Table gave the results of some careful trials made recently with a Belliss-Morcom triple-expansion engine, which showed not only the general economy of superheated steam but also the effect of superheating on the mean pressure in the cylinders, and on that in the condenser, the loads, the rates of revolution, and the speeds of the air- and circulating-pumps being similar in both experiments. Some engineers were fearful of steam getting over-superheated when standing, and so hot that, on restarting, the cylinders and their fittings might be seriously damaged. This was a mistake, for steam was a bad conductor of heat, and when there was no circulation in the superheater there was practically no rise in temperature. Better founded was the fear that under such circumstances the tubes, etc., of the superheater might become dangerously hot. It would seem to be a simple preventive if, connected with the control-valve of the engine, there were means for automatically shutting off heat from the superheater; with a single tube or a pair of large tubes in a locomotive-boiler this could be done.

Mr. Seaton.

TRIALS OF A BELLISS-MORCOM TRIPLE-EXPANSION ENGINE.

(1) With saturated steam, (2) with superheated steam: cylinders, 13½ inches, 20½ inches, and 30 inches in diameter, by 14 inches stroke; speed, 350 revolutions per minute.

		(1) Dry Saturated Steam.	(2) Superheated Steam.
Boiler-pressure during trials . . . Lbs. per sq. in.		180	177
Steam-pressure at high-pressure cylinder valve-box . Do.		173	172
„ temperature at high-pressure cylinder valve-box		385° F.	500° F.
Vacuum in condenser . . . . Ins.		24·8	26·2
E.HP. Steady load throughout		537·0	537
I.HP.	High-pressure cylinder	222·0	233
	Intermediate-pressure cylinder	186·5	183
	Low-pressure cylinder	208·0	196
Total I.HP. of system		616·5	614
Steam-consumption per kilowatt-hour . . . Lbs.		23·4	18·26

Saving of steam, 22 per cent.

Mr. Vaughan.

Mr. H. H. VAUGHAN, of Montreal, stated that the use of superheated steam in locomotives was introduced on the Canadian Pacific Railway as a regular practice in 1904. Before that date three engines had been equipped experimentally with Schmidt superheaters, the first with the smoke-box type shown in Fig. 2, Plate 1, and the two following engines with the type shown in Fig. 3, Plate 1. The results were so satisfactory that it was decided to apply superheaters to twenty "Consolidation" goods-engines which were purchased in October and November, 1904. The experience with these engines confirmed the results previously obtained, and since then every goods- and passenger-locomotive purchased or constructed for the Canadian Pacific Railway had been fitted with superheaters: in addition a large number of engines constructed previously had been so equipped, and at the present time, out of a total of 2,201 engines in service, 1,525 had superheaters. Of 266 shunting-engines included in the 2,201, 43 had been equipped, the application of superheaters to shunting-engines having been introduced only recently. In 1905 he stated[1]

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[1] H. H. Vaughan, "Use of Superheated Steam on Locomotives," Proceedings Am. Master Mechanics Association, 1905, p. 113.

Mr. Vaughan. that the saving of fuel was 10 to 25 per cent. in goods-service, and 15 to 20 per cent. in passenger-service; and the subsequent experience had shown no reason to modify these figures. While considerably greater economy might be obtained under certain conditions, in Canadian practice a certain quantity of fuel was used for working air-brakes and electric headlight equipment, and for heating trains, in which no saving was obtained. In goods-service a certain portion of the fuel was lost when the engine was standing idle; and taking all these factors into consideration, he considered the estimate given by him in 1905 was a reasonable one for the conditions in Canada. Experience showed that while some saving was obtained by applying superheaters to compound locomotives, a compound superheater engine would save only 5 per cent. in coal over a simple superheater engine of similar design; and it was not considered desirable to retain the complication of compound engines over simple engines for a saving of 5 per cent., especially in view of the greater flexibility of the simple engine. There had been practically no troubles connected with the introduction of the superheater. The use of piston-valves had previously been established as standard practice on the Canadian Pacific Railway, and the same design of piston-valve was used for the superheater locomotive as for the saturated-steam locomotive. No trouble was experienced with these valves with superheated steam; in fact, there was no difference in their performance with either saturated or superheated steam. The only part of the locomotive that gave more trouble with superheated steam was the piston packing-ring. The life of these rings was reduced from 60,000–90,000 miles with saturated steam to 10,000–15,000 miles with superheated steam. This life appeared to vary considerably in the different classes of engines and the different kinds of service, but there had been a decided difference in this respect. In general, however, an engine equipped with a superheater cost no more to maintain than an ordinary simple engine, as the reduction in the cost of boiler-repairs and the avoidance of trouble from the presence of water in the cylinders of superheaters on shunting-engines had proved very satisfactory, possibly not because they really used superheated steam, but because the ordinary locomotive in shunting service used exceedingly wet steam, and the superheater improved this condition to a certain extent. Generally speaking, he considered that the use of superheated steam in locomotives over a period of 10 years had been uniformly satisfactory, and that its advantages were beyond question.

Mr. J. T. Wallis, of Altoona, Pa., stated that the experience of the Pennsylvania Railroad Company during the past 2 years was so much in accord with the views expressed in the Paper that he found very little from which to dissent. There were a few matters, however, in which the difference between British and American practice was worthy of note. While his conclusions in regard to mechanical lubricators confirmed the desirability of double-acting pumps, it had not been found necessary to deliver oil to so many points as were recommended in the Paper. His Company were experimenting with two systems. In one the oil was delivered to the steam-pipe just above the valve; in the other the oil was applied to both the valve-chest and the cylinders. The results appeared to suggest that it would be well if all the oil were delivered to the steam-pipe. The mechanical lubricators experimented with in the United States had not been strong enough to withstand service well, and while they had worked satisfactorily in the matter of lubrication, the various parts of the lubricator itself had not been sufficiently strong, in consequence of which they had broken, causing a great deal of trouble. A new lubricator had recently been designed, which was much stronger, and this was about to be put on locomotives experimentally. In it steam-pipe lubrication alone had been provided for. In comparing the results of tests made in actual running with those of the tests between London and Leeds and between London and Derby, Mr. Wallis found that greater economy was obtained than was reflected by the English tests, and he believed this to be due to the fact that the locomotives used between London and Leeds were probably underloaded, whereas his were more fully loaded in relation to the maximum power of the locomotive. His Company found—as he believed every one else found—that the superheater gave its best performance when the locomotive was fully loaded. With regard to the Author's suggestion as to the desirability of making some tests to determine the variation in water rate with varying superheat, Mr. Wallis had made tests to determine that point, but rather than attempt to incorporate all the results in this communication he had forwarded the data directly to the Author for his information. Mr. Wallis.

The Author, in reply, expressed his interest in the experiments carried out by Mr. Adams. He would have thought that cast-iron packing-rings would not bed up readily to the piston-rod and that the wearing of the two metals would not have been found satisfactory. The experience of Mr. Maréchal and Mr. Dubois with superheater engines without damper-doors was also interesting. If The Author.

The Author. it could be shown that these doors were unnecessary, considerable economy would be effected in first cost and also in maintenance. Apart from other considerations, however, the Author thought there might be a tendency for the large flues to soot up while steam was being raised if no dampers were provided. With regard to Mr. Fry's conclusions, the water-consumption per ton-mile was the quantity actually used from the tender, the temperature of the water ranging from 40° to 60° F. As to the drop in pressure between the regulator and the steam-chest, the tests showed that with a restricted regulator-opening—as usually was the case in service on the road—the superheater engine in all cases gave a higher pressure in the steam-chest than the saturated-steam engine, the regulator-opening, cut-off, boiler-pressure, and speed being as nearly as possible the same in each case. The higher pressure might be due partly to the wetness of the steam passing into the superheater, where its moisture was evaporated, thus causing a higher pressure than would be the case otherwise; in addition to this, the tendency of the volume of the steam to increase when superheated had to be considered. The question of the increase of power given by superheating, to which Professor Goss had referred, was one of the utmost importance to railway-engineers. The Author quite agreed with Mr. Hughes that air-valves, to be of any benefit, should be large. The air-valves referred to in the Paper were of the type which admitted air and steam to the cylinders. It had been found that the deposit in the cylinders of the Midland engines fitted with by-passes was very different from that given by Mr. Hughes. Analysis showed that it was derived largely from the oil, a sample being as follows:—

	Per Cent.
Non-oily combustible matter, chiefly carbon	77
Thick brown oil	12½
Ash, chiefly ferric oxide	10½

The object of turning ribs or grooves on the large tubes was to prevent leakage, and not to stop them from drawing out of the plate. The figures Mr. Hughes had given of the mileage and consumption of his goods-engines were of great interest, extending as they did over so long a period, and coming from one who, the Author believed, was the first in England to use superheating at all extensively. The results Mr. Hume had obtained with superheater locomotives were excellent, and doubtless the high percentage of saving of coal and water was largely due to the superheater engine being better able to deal with its work. The great advantage of superheating was obvious in places where coal had to be imported at a high price.

The Author. With regard to Mr. King's remarks, the Author was under the impression he had proved clearly his statement that with the use of superheated steam a boiler could be worked at a lower pressure, or if the same pressure was maintained it could do the same work without being so hardly pushed; that had certainly been borne out by the experience of all the locomotive-superintendents and others who had taken part in the discussion. The points which appealed to practical locomotive-engineers were the consumption of water and of fuel, and the capacity of a locomotive to deal readily with its train. He considered it had been proved conclusively that in all these three essential points a locomotive using superheated steam was far in advance of one using saturated steam, and therefore he need not go further into the matter. In reply to Mr. Pickersgill, as stated, the diagrams shown in Figs. 20, Plate 2, had been taken with as nearly as possible the same regulator-opening, cut-off, boiler-pressure, and speed. Under these similar conditions of engine-working, the superheater engine developed considerably more power than the saturated-steam engine, and in order to obtain diagrams with both engines working as stated above, those from the superheater engine had been taken at such a point that a higher horse-power was required to work the train at the speeds given. The diagrams shown in Figs. 19 were comparable as regarded speeds and cut-off, but in the case of the superheater engine the regulator-opening was less than in that of the saturated-steam engine. The Author was quite satisfied that, at any rate at the speeds mentioned by Mr. Pickersgill (40 to 60 miles per hour), the tractive force developed by superheater engines was decidedly greater than that of similar saturated-steam engines. The Author realized, as all who had followed Dr. Schmidt's work must have done, the great importance of the ratio of the flue-areas and heating-surfaces of the superheater to those of the ordinary boiler-tubes, in regard to the degree of superheat obtained. The experimental tests referred to by Mr. Seaton had been of absolutely positive type, in that they had consisted simply of comparisons between the quantities of coal and water used during the performance of certain definite work, care being taken to eliminate, as far as possible, the variations due to weather, etc. The Author was fully aware that the same fine degree of comparison that was obtainable with stationary engines could not be looked for in such tests. It was necessary to have a sharp bend in the superheater element which had to go into a comparatively-speaking small fire-tube. The bend was not obtained by folding the pipe, but by cutting and welding. It was interesting to have remarks from an

The Author. engineer of such long experience of superheating as Mr. Vaughan, and the results of his experience, extending over 10 years, could not fail to have great weight with any one engaged in locomotive practice. The information which Mr. Wallis referred to as having been supplied directly to the Author showed that from tests Mr. Wallis had made with the degree of superheat ranging from zero to 300° F., for every increase in superheat at every cut-off there was a saving in steam; for instance, with 15 per cent. cut-off at about 1,000 feet per minute piston-speed, for every 20° rise in superheat there was a reduction in the water-consumption of 1 lb. per indicated horse-power-hour, and at 50 per cent. cut-off it required 40° rise in superheat to give the same reduction. Mr. Wallis had furnished other interesting information, particularly with regard to the effect of various lengths of superheater elements, etc., which would no doubt be published in due course. The Author regretted that he had overlooked tests made by Professor Goss in 1912, which showed the economy of various degrees of superheat.[1]

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[1] Bulletin No. 57, University of Illinois, p. 63.

20 January, 1914.

ALEXANDER ROSS, Vice-President,
in the Chair.

The discussion upon Mr. Henry Fowler's Paper, "Superheating Steam in Locomotives," occupied the evening.

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27 January, 1914.

BENJAMIN HALL BLYTH, M.A, Vice-President,
in the Chair.

The CHAIRMAN said the members were aware of the serious loss which not only The Institution but the whole country had lately suffered by the death of Lord Strathcona, and the Council at its meeting that afternoon had passed the following resolution, in which he was sure the members would concur:—

"That the Council have learned with deep regret of the death of Lord Strathcona and Mount Royal, who has been an Honorary Member of The Institution since 1905, and whose distinguished services to Canada, notably in the development of railway and other enterprises, have proved of incalculable value to the Dominion and thereby to the British Empire."

The discussion on "Superheating Steam in Locomotives" was then continued and concluded.

3 February, 1914.

GEORGE ROBERT JEBB, Vice-President, in the Chair.

The Council reported that they had recently admitted as

Students.

Richard Clerke Brown.
James Douglas Chassereau, B.Sc. (Engineering) (*Lond.*).
Clarence Algernon Currie.
James Thurstan Dukinfield Darbishire.
Eric Charles Gibbons.
Allan Peter Hitchens, B.Eng. (*Liverpool*).
Harry George Hoare.
William Hodgson.
John Bertram Jordan.
Leslie Ward Lane.
John Wilson Norris.
Charles James Paterson, B.Sc. (Engineering) (*Lond.*).
Norman Shairp, B.A. (*Oxon.*).
Robert Tofield Sinclair.
Stephen Oswald de Souza.
Richard Stansfield.
Francis White, B.Sc. (Engineering) (*Lond.*).
Francis Stanley Woodcock.

The Scrutineers reported that the following Candidates had been duly elected as

Members.

Alfred Oscar Kolkhorst.
Edward Tindale, B.C.E. (*Melb.*)

Associate Members.

Herbert Thomas Allen.
Richard Nunn Aylward.
George James Bertinshaw.
George Arthur Bridges.
George Carlyle, B.A., B.E. (*Royal*).
Joseph Arnold Cooksey.
Ferdinand Leslie Creswell.
John Whitehead Wilson Drysdale, Jun., B.Sc. (*Glas.*)
Arthur Dudgeon, B.A.I. (*Dubl.*)
Lawrence Samuel Durrell.
Percy Tucker Easton, Stud. Inst. C.E.
Joseph Arthur Ellis.
Albert Leonard Evans, Stud. Inst. C.E.
Arthur Hearle Fenwick, B Sc. (Engineering) (*Lond.*), Stud. Inst. C.E.
Charles Strong Galbraith, B.C.E. (*Melb.*).
William Gott Gibson, Stud. Inst. C.E.
Stanley Herbert Harris, B.Sc. (*Wales*).
Cuthbert Hartnell.
Charles Cuthbert Harward.
Arthur Cecil Hewitt.
Arthur James Hillman.
John Dudley Holmes.
Edward Henry Hughes.
Edward Cecil Ingleby, Stud. Inst. C.E.
Herbert Alfred Jackson, B.C.E. (*Melb.*).
Arthur Cyril Jennings.
Arthur William Mosley Jesson.
Naorosji Dadabhai Katrak, L.C.E. (*Bombay*).
Charles Macritchie Low, B.Sc. (*Edin.*), Stud. Inst. C.E.

Associate Members—continued.

John Weyman Mason, B.Sc. (Engineering) (*Lond.*), Stud. Inst. C.E.
John Halliwell Mawson, B.Sc. (*Leeds*), Stud. Inst. C.E.
James Murray Morice, B.Sc. (*Edin.*).
Richard Douglas Morris, B.Sc. (Engineering) (*Lond.*).
John Norris.
Cecil Joseph Parker, Stud. Inst. C.E.
Leonard William Peach, Stud. Inst. C.E.
Keith Rae Shand.
Henry Hey Sharp.
Ernest Walter Stedman, Stud. Inst. C.E.
John William Abbott Steggall, B.Sc. (*St. Andrews*).
Arthur Ridley Temperley, B.A. (*Cantab.*), Stud. Inst. C.E.
Richard Samuel Thompson.
William Martin Veitch, Stud. Inst. C.E.
Alexander Smillie Wansbrough.
Randolph Cecil Wells, B.A. (*Cantab.*).
Tom M'Call White, Stud. Inst. C.E.
Harold Launcelott Wilkinson, M.C.E. (*Melb.*).
William Lyon Wood, B.A. (*Cantab.*).

(*Paper No. 4063.*)

"The Problem of the Thrust Bearing."

By Henry Thornton Newbigin, Assoc. M. Inst. C.E.

The ordinary pivot or collar thrust bearing is well known to be very inefficient as compared with an oil-lubricated journal bearing. It has a much higher frictional loss, combined with a lower carrying-capacity. The object of this Paper is to show how this difference is to be accounted for and how it may be overcome.

The journal bearing in its simplest form is merely a round shaft revolving in a cylindrical support. It was first used on account of its simplicity and not because of any preceding theoretical investigations. It has proved, however, to be a very efficient mechanism when properly lubricated.

On the other hand, the thrust bearing—which consists merely of a collar or collars on a shaft pressing against one or more annular supports—has proved to be very inefficient.

It is evident that there must be in the first type of bearing some condition, favourable to low friction combined with a high carrying-capacity, that does not obtain in the second.

The reason for the low frictional loss in a properly lubricated journal bearing has been known for some years, and the theory of the subject has been set forth, but the application of this theory to the design of an equivalent thrust bearing is of quite recent date.

Considerable numbers of thrust bearings are now being made which have a mechanical efficiency quite as high as the best oil-lubricated journal bearings, combined with the same high load-carrying capacity.

In low-speed machines high mechanical efficiency is of less importance than in those running at higher speeds, because in the former the heat generated by friction is dissipated by radiation and conduction, while in the latter the heat is generated too quickly for this, and bearing troubles ensue. This difficulty has been felt more of late years, owing to the higher speeds at which many kinds of machinery are run, and particularly in the case of thrust bearings, because of their greater friction. Any improvement in this type of bearing is therefore of value to engineers, especially if the principle underlying it helps towards a clearer understanding of the general theory of lubrication.

A large amount of experimental investigation of the laws of friction has been carried out, but the deductions made from the experiments are so conflicting as to reduce largely their value to engineers.

This lack of agreement arose from attempts to explain different kinds of phenomena by one set of laws.

As long ago as 1781 Coulomb experimented and enunciated four laws covering the phenomena of the friction between surfaces of solid bodies in contact. In his investigations he took into account four factors, on which he based his laws, namely:—

(*a*) The area of the surfaces in contact.
(*b*) The force pressing them together.
(*c*) The speed of rubbing.
(*d*) The force necessary to produce sliding motion.

Subsequent experimenters confirmed Coulomb's laws in so far as they applied to dry surfaces—at least within limits of pressure of ¾ lb. to 100 lbs. per square inch, and rubbing-speeds up to 10 feet per second. No satisfactory formula was found, however, to express the friction between lubricated surfaces.

This failure was shown by the late Professor Osborne Reynolds, F.R.S., M. Inst. C.E.,[1] to be due to the fact that, between perfectly lubricated surfaces, the conditions are essentially different from dry friction, and follow entirely different laws. Moreover, between the limits of dry friction and perfect lubrication there is a gap which cannot be covered by any law common to both.

Friction is the term used to denote the resistance offered to relative tangential motion between two bodies in contact. The same term is used whether the bodies are two solids in actual contact or are separated by balls or rollers. It is also used to express the resistance between a solid and a liquid or between two solids completely separated by a liquid, such as occurs in a perfectly lubricated bearing.

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[1] Phil. Trans. R. Soc., vol. 177, p. 157.

In the last case, while the term is convenient, it is apt to lead to confusion of ideas when dealing with the theory of such bearings.

"Coefficient of friction" is the term used to denote the ratio between the tangential force necessary to produce relative motion of two surfaces in contact and the radial or normal force pressing the surfaces together. This term also has not the same significance when applied to the friction between a liquid and a solid.

As is well known, Coulomb deduced from his investigations that the friction between two solid bodies is proportional to the total force between them, and is independent of either the areas in contact or the speed of rubbing. It depends merely on the nature of the surfaces; consequently, to secure a low frictional loss it is necessary to use materials which have by their nature a low friction-constant. This is the argument in favour of using anti-friction metals in bearings. The subject is not capable of any mathematical treatment, but is merely a question of experience.

Further investigations into the subject of lubricated journal bearings have shown that, while Coulomb's laws are approximately true for greasy surfaces, they do not hold good when an ample supply of oil is provided; under such conditions the friction falls to a mere fraction of what it was before.

This phenomenon was attacked from the mathematical side by Professor Osborne Reynolds,[1] who showed that the resistance to turning in a well-lubricated bearing was due only to the viscosity of the oil. This is his "hydrodynamic theory of lubrication," and the mathematical investigation of the subject agrees very closely with the results of actual tests on journal bearings in what has been called a state of "perfect lubrication."

The laws applying to this state are entirely different from those of dry friction, and the inconsistency of the formulas deduced by many experimenters was due to the fact that in starting from rest a journal bearing first acts according to Coulomb's laws, and if or when it reaches a state of "perfect lubrication" it acts in accordance with the laws of the flow of viscous substances.

These two sets of laws may be stated side by side for comparison (p. 226), and it will be seen that the terms "Friction" and "Coefficient of Friction" are used in connection with two kinds of resistance, and that the laws followed by one kind are the opposite of those followed by the other. It is not surprising, therefore, that attempts to find one formula to express both kinds of friction were not successful.

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[1] "On the Theory of Lubrication, etc." Phil. Trans. R. Soc., vol. 177, p. 157.

Comparison of the Laws followed by the Friction of Dry and of Perfectly Lubricated Surfaces.

Dry Surfaces.	*Perfectly Lubricated Surfaces.*
The force required to maintain motion within the limits previously stated is	The force required to maintain motion is
1. Independent of speed.	1. Proportional to speed.
2. Independent of area.	2. Proportional to area.
3. Proportional to the force pressing them together.	3. Independent of the force pressing them together.
4. Dependent only on the nature of the surfaces.	4. Dependent only on the viscosity of the lubricant.

As will be shown later, the difference between the laws of dry friction and those of perfect lubrication is not quite as great as would appear at first sight, because in the latter the viscosity of the lubricant necessary to produce perfect lubrication is

(1) Inversely proportional to the speed.
(2) Inversely proportional to the area.
(3) Proportional to the pressure per square inch.

The comparative ratios of length to width of the surfaces must also be taken into consideration.

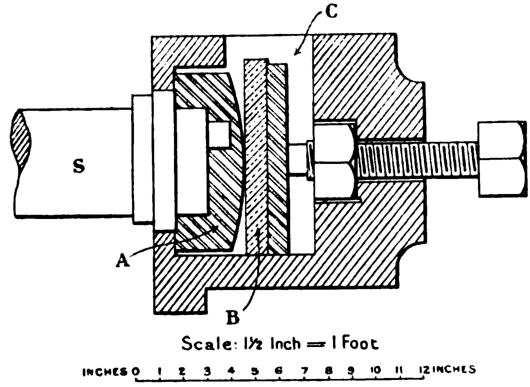
At the speeds of rubbing usually found in bearings, the coefficient of friction for smooth dry surfaces ranges from about 0·06 for some anti-friction metals and steel to about 0·15 for cast iron and steel; but when the surfaces are lubricated properly the coefficient may fall to 0·0012 or less. This figure is commonly obtained in the better class of journal bearings, and the object of this Paper is to show how an equally low frictional loss may be secured in a thrust bearing.

Thrust bearings may be divided into two classes, namely, pivot bearings and collar bearings.

Fig. 1 shows a pivot thrust bearing, such as is sometimes used in the worm-shaft of a brick-making machine. The end of the shaft S is fitted with a steel shoe A, which bears against a gun-metal plate B. The pressure is very high when the plate B is new, and is usually about 1,200 lbs. per square inch when it becomes worn hollow. The box C is kept full of grease, but this is not of much use in reducing the friction, owing to the high pressure squeezing the grease out. A bearing of this type is very inefficient.

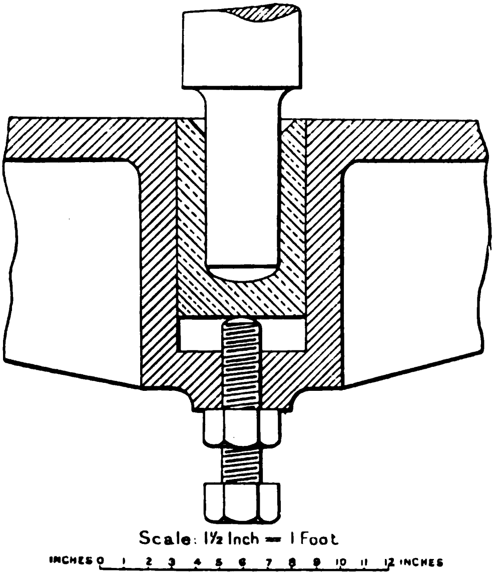
Fig. 2 shows an ordinary footstep bearing, such as is used in some water-turbines. The load is usually about 1,000 lbs. per square inch, under which pressure efficient lubrication is not practicable, and in practice the coefficient of friction is about the same as for dry metal surfaces rubbing together. Wear is rapid, and ample means of adjustment must be provided.

Fig. 1.


C
S
A
B
INCHES 0 1 2 3 4 5 6 7 8 9 10 11 12 INCHES

Scale: 1½ Inch = 1 Foot

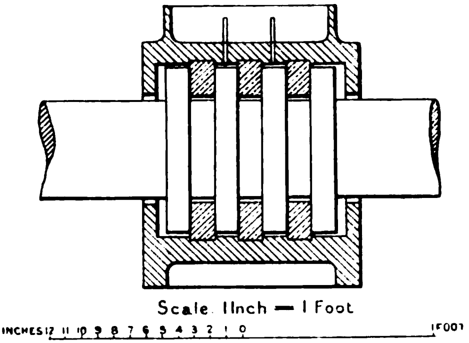
Fig. 2.


INCHES 0 1 2 3 4 5 6 7 8 9 10 11 12 INCHES

Scale: 1½ Inch = 1 Foot

Fig. 3 shows a section of an ordinary collar thrust bearing. Owing to the longer radius at which the friction acts in this type, it is essential to keep the coefficient of friction within reasonable limits. The only way in which it has been possible hitherto to do this is by limiting the pressure between the surfaces to one below which the oil can work itself in and so reduce the friction. This is done by adding collars to the shaft until sufficient area is obtained to reduce the pressure to 50 or 60 lbs. per square inch. At such a pressure a collar thrust bearing will work with a coefficient of friction of about 0·03.

Fig. 3.



The late Mr. Beauchamp Tower,[1] M. Inst. C.E., found that 75 lbs. per square inch was the maximum load that could be borne safely under favourable conditions.

The following comparison of the friction-coefficients and load-carrying capacities of pivot, collar, and journal bearings shows the great inefficiency of pivot and collar thrust bearings as compared with a journal bearing in a state of perfect lubrication.

Type.	Lbs. per Square Inch.	Average Coefficient.	Condition of Surface.
Pivot thrust	1,000/1,200	0·10	Dry
Collar „	50/60	0·03	Greasy
Journal bearing	500/600	0·0025	Perfect lubrication.

If a journal bearing is run with the surface dry the friction will be similar to that of a pivot bearing, and if the supply of oil is insufficient the friction will be similar to that of a collar bearing. There is, however, the important difference that with a sufficient supply of oil the friction of the journal bearing will fall to that of perfect lubrication, whereas that of the other two types will not. In order to find out why this is so it is necessary to consider first exactly how the change from greasy friction to perfect lubrication occurs, and whether it is sudden or gradual as the speed of a journal bearing increases from dry surfaces at rest to perfect lubrication at running speed.

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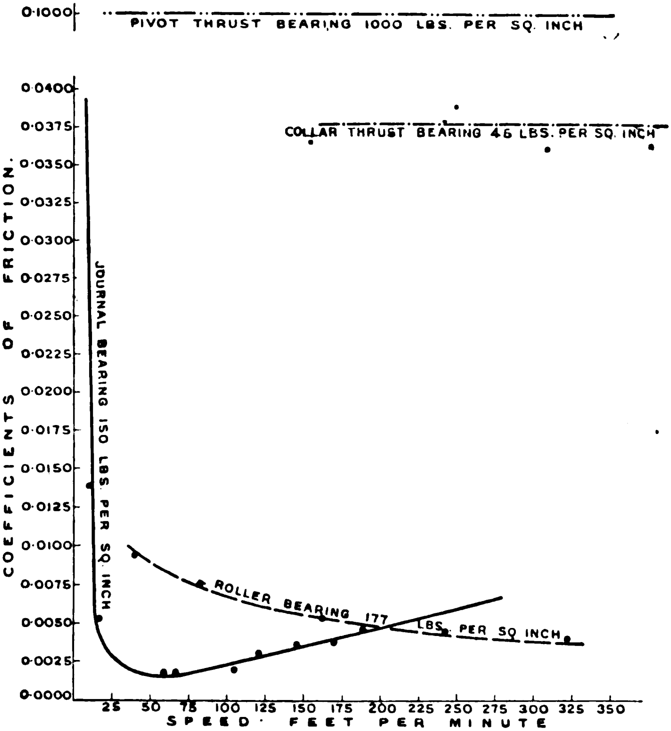
[1] Proc. Inst. Mech. Eng., 1888, p. 177.

Fig. 4 shows the changes in the coefficient of friction for different types of bearings as the speed increases.

Starting at the top of the diagram[1] the first line shows the coefficient of friction for a pivot bearing with dry surfaces, which is given as 0·1000; the actual value, however, depends on the nature of the surfaces and may be less or more than that figure; the important points are that it is very high as compared with the next type of bearing, and that it follows Coulomb's law and is independent of speed.

Fig. 4.



The next line gives the results obtained by Mr. Tower[2] for a collar bearing under a load of 45 lbs. per square inch, and shows that the coefficient of friction follows the same law very nearly. Mr. Tower found that between pressures of 15 and 90 lbs. per square inch and at rubbing-speeds of 170 to 442 feet per minute, the lowest coefficient of friction was 0·029 and the highest 0·065. Inspection of his results shows that the actual friction approximates closely to Coulomb's law, in being nearly independent of either speed or area and proportional to pressure, as in the case of the pivot bearing; but in order to obtain these results the intensity of pressure must be limited, as already pointed out.

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[1] It should be noted that this diagram is broken between the coefficients 0·1000 and 0·0400, in order to shorten the Figure.—H. T. N.

[2] Proc. Inst. Mech. Eng., 1888, p. 177.

The curve marked "Journal Bearing" is taken from Tables by Professor Goodman,[1] and shows that the friction is high at starting, but that as soon as a speed of about 10 feet per minute is attained there is a sudden fall in the coefficient of friction to a small fraction of the starting-friction, and then a slow gradual rise, which, as will be shown later, follows Professor Osborne Reynolds's hydrodynamic theory of friction.

In pivot or collar thrust bearings, then, the friction follows Coulomb's laws for all ordinary loads and speeds, while a properly lubricated journal bearing passes rapidly through this stage in starting and then follows the laws of the flow of viscous substances.

The curve marked "Roller Bearing" has been taken from a Paper by Professor Goodman[2] and is added for comparison. The load and speed are taken as in the journal bearing.

The saving in the use of roller and ball bearings is in their low static friction rather than in their low running friction.

In continuous-running machines, such as steam-turbines or centrifugal pumps, a low starting-friction is of less importance than reliability and simplicity.

It should be noticed in the curve for a journal bearing that, as the friction is independent of the load after the change has taken place, the slope of the curve for actual frictional resistance is the same as for the coefficients of friction.

MR. BEAUCHAMP TOWER'S EXPERIMENTS.[3]

In the earlier experiments on the friction of lubricated bearings difficulty was found in fixing a definite measure of the quantity of oil supplied. Mr. Tower adopted the method of putting the brass on the top of the shaft, and allowing the shaft itself to run in an oil-bath and take up as much oil as it would. He also tried supplying the oil through a hole on the top of the brass, but found that the oil spurted out of this hole, being carried up out of the oil-bath by the rotation of the shaft. He then fitted a pressure-gauge to the hole, and found that the surfaces were entirely separated by a pad or film of oil, in which the pressure at the oil-hole was much higher than the average pressure over the whole surface of the bearing. Continuing his investigations, he had a brass made in the manner shown in *Figs. 5*, with which he tested the pressure at about fifteen points on its surface. These pressures he plotted in the series of curves shown, from which it appeared that the pressure was zero around the edges of the brass, and rose to the maximum at a point past the centre-line at half the length of the journal.

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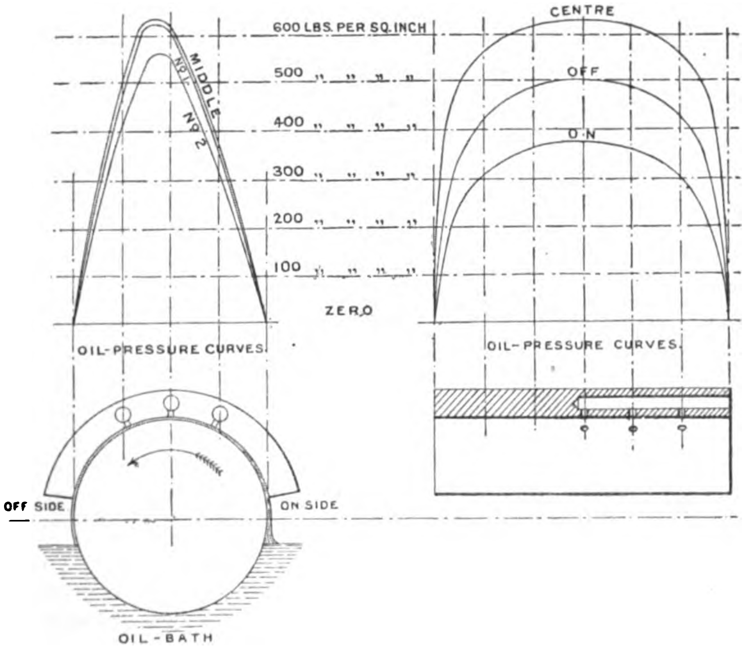
[1] Transactions Manchester Assoc. of Eng., 1890, p. 128, Table X (a).

[2] Minutes of Proceedings Inst. C.E., vol. clxxxix, p. 116.

[3] Proc. Inst. Mech. Eng., 1883 and 1885.

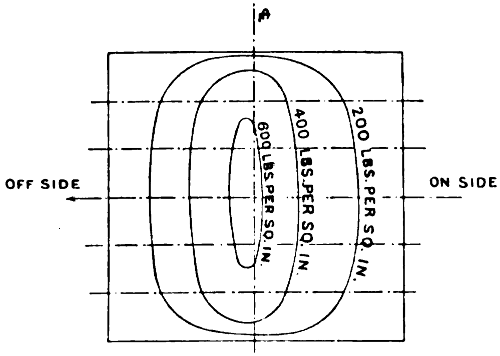
Figs. 5.



CROSS SECTION LONGITUDINAL SECTION.

The curves which he obtained are shown in the upper portion of *Figs. 5*, while the cross section shows the manner in which the oil is dragged in between the surfaces of the brass and shaft by the rotation of the latter. If, instead of the curves being plotted on a series of vertical planes, the brass be assumed to be opened out flat, and lines be drawn through the points of equal pressure, a diagram like *Fig. 6* is obtained, which represents lines of equal pressure in the oil-film, starting from zero around the edges and reaching the maximum pressure around a point situated a little past the centre of the figure in the direction of motion.

Fig. 6.



LINES OF EQUAL OIL-PRESSURE.

For such a distribution of oil-pressure to be maintained in a bearing two conditions are essential:

(1) The surfaces must be at an inclination to each other, with the angle of inclination facing the entering oil-film.

(2) There must be at least two points of "no pressure," one at which the oil can enter and one at which the used oil can leave.

In a journal bearing the inclination of the surfaces takes the form of a curved wedge, which is brought about by a slight shifting of the centre of the shaft in relation to the centre of the brass, and points of "no pressure" occur on the "on" side and "off" side of the oil-film, which is brought up by the rotation of the shaft. But in a pivot or collar bearing of the ordinary types neither of these two essential conditions is present; therefore the low coefficient of friction due to the viscous flow of the lubricant is not found.

Mr. Tower found that a journal bearing which, when lubricated from below by means of an oil-bath, would carry continuously a load of more than 600 lbs. per square inch, would not run cool under a load of only 100 lbs. when it was supplied with oil from the top by a hole drilled through the brass, even with an oil-groove cut along the under surface.

It is evident from the foregoing that the condition to be aimed at in a lubricated bearing, or indeed between any pair of lubricated surfaces, is to design the parts so as to secure a continuous and true state of viscous flow within the oil-film rather than two greasy metal surfaces rubbing together.

The conditions necessary for this between any pair of surfaces are capable of mathematical determination, and they happen to be present in many journal bearings; but they do not occur in pivot or collar thrust bearings of the ordinary types.

In order to show what these conditions are, it is necessary to examine the nature of viscous flow and to show from the results of actual experiments that the friction in a properly lubricated bearing does, in fact, partake of this nature.

The mathematical investigation of the subject of viscous flow is beyond the scope of this Paper, but one or two resulting formulas for calculating the friction of plane surfaces will be cited; for the rest the original publications to which reference is made should be consulted.

VISCOSITY.

A liquid or semi-solid which has the property of adhering to a surface and cohering among its particles is said to be viscous; e.g., pitch and oil are viscous substances. Viscosity is the resistance which a viscous substance offers to distortion or change of shape.

The viscosity of a substance may be measured either relatively to that of another substance or in terms of units of time, space, and force. The units usually employed for measuring the absolute viscosity are the centimetre, gramme, and second, the force being given in dynes per square centimetre.

There are two kinds of viscous resistance. The first is physical viscosity, which is the resistance to flow offered by fluids in pipes of small diameter, or at low speeds, and by thin films. This resistance is directly proportional to the rate of flow, and is that which occurs in perfectly lubricated bearings. The second is mechanical viscosity, which is the resistance of fluids in pipes of larger diameter, or at higher velocities, and of bodies moving in free liquids. This resistance is proportional to the square of the speed. The extra resistance is caused by the formation of eddy-currents within the liquid, which interrupt its flow.

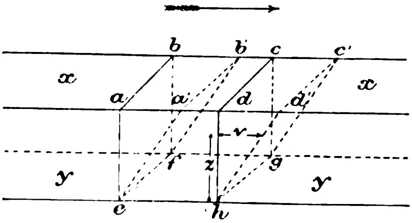
It is doubtful if the resistance in the oil-film of a bearing is ever that due to mechanical viscosity at any ordinary speeds.

Viscosity varies with temperature, the resistance falling as the temperature rises, in a curve which depends on the nature of the substance.

In *Fig. 7* let *x x* and *y y* represent two parallel plane surfaces of infinite extent, between which there is a viscous substance which adheres to the surfaces. Then any tangential motion between the planes will cause a distortion within the substance. This distortion is of the nature of a shear within the viscous body.

Let *a b c d e f g h* represent a unit cube of the substance. Then if the plane *x x* is moving at a uniform rate in a direction parallel to *y y*, the distortion will vary uniformly from 0 at *y y* to the full amount of the displacement at *x x*.

Fig. 7.



Suppose the surface *a b c d* to have moved to *a' b' c' d'* in 1 second; then, as the rate of distortion is uniform, the lines *d' h* and *c' g* will be straight, and *v* will represent the amount of the distortion at any distance *z* above *y y*. Also the wedge *c d g h c' d'* will represent the volume of the substance passing the vertical plane *c d g h* per second.

The rate of distortion is $\frac{v}{z}$.

Let *f* denote the force required per unit of area to produce this rate of distortion . . . . (i)

Then *f* will vary as the rate of distortion. . . . . . . (ii)

Let λ denote the coefficient of viscosity.

Then $f = \lambda \frac{v}{z}$

And $\lambda = f \frac{z}{v}$ . . . . (iii)

The coefficient of viscosity (commonly called the viscosity) is then the force per unit of area necessary to cause unit rate of distortion or flow in a viscous substance; and the absolute viscosity in C.G.S. units is the force in dynes per square centimetre which will cause a film 1 centimetre thick to flow at the rate of 1 centimetre per second.

THE RESISTANCE OF OIL-FILMS TO VISCOUS FLOW.

Since the rate of distortion is proportional to the tangential speed of the surfaces for a given thickness of oil-film, the resistance to be overcome is proportional to the speed . . . . (1)

If f denotes the resistance per unit of area, see (i),
and A „ „ whole area,
then Af „ „ whole resistance,
and the resistance is proportional to the area . . . . . . (2)

It has been shown by experiments that if the pressure in the oil-films can be maintained:—

The resistance is independent of the pressure . . . . . . (3)

From definition (iii) it is evident that:—

The resistance is proportional to the viscosity of the lubricant (4)

Before proceeding to examine the conditions necessary for the maintenance of the pressure in the oil-film, as required by (3), it is worth while to see whether the laws stated above are confirmed by the results of actual tests.

TABLE I.—TOWER'S EXPERIMENTS.[1]

Journal bearing 4 inches in diameter and 6 inches long running in a bath of olive oil at a temperature of 90° F. Chord of arc of contact = 3·92 inches. The nominal area is 4 inches by 6 inches.

	Feet per Minute.							
	105	157	209	262	314	366	419	471
Nominal Load.	Frictional Resistance in Lbs. per Square Inch.							
Lbs. per Sq. In.								
520	..	0·416	0·520	0·624	0·675	0·728	0·779	0·883
468	..	0·514	0·607	0·654	0·701	0·794	0·841	0·935
415	..	0·498	0·580	0·622	0·705	0·787	0·870	0·995
363	..	0·472	0·580	0·616	0·689	0·725	0·798	0·907
310	..	0·464	0·526	0·588	0·650	0·680	0·742	0·835
258	0·361	0·438	0·515	0·592	0·644	0·669	0·747	0·798
205	0·368	0·430	0·512	0·572	0·613	0·675	0·736	0·818
153	0·351	0·458	0·535	0·611	0·672	0·718	0·764	0·871
100	0·360	0·450	0·550	0·630	0·690	0·770	0·820	0·890

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[1] Proc. Inst. Mech. Eng., 1883.

(1) Reading the lines horizontally, it is seen that the frictional resistance increases with the speed for each pressure given, but not quite in direct proportion to the speed. Professor Reynolds pointed out that the friction heats the oil-film and reduces the viscosity of the oil, and consequently the resistance is less than in a direct ratio to the speed, as required by the theory.

(2) Reading the columns vertically, it is seen that, for any given speed, the resistance is independent of the pressure. (See also Table II.)

TABLE II.—GOODMAN'S EXPERIMENTS.[1]

Bath lubrication: temperature, 40° C.; revolutions, 233 per minute; length of brass, 4 inches; diameter of shaft, 2 inches. The loads and frictional resistances are the total amount expressed in pounds.

	Arcs and Chords of Bearing Brasses.				
	2 ins. 180°	1·75 in. 122°	1·5 in. 97°	1 in. 60°	0·5 in. 0·29°
Total Load in Lbs.	Frictional Resistance in				
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
50	2·20	2·29	2·09	1·05	0·63
100	2·88	2·38	2·09	1·05	0·84
150	2·88	2·40	2·10	1·05	0·84
200	3·18	2·42	2·12	1·10	0·84
250	3·20	2·42	2·12	1·10	0·84
300	3·09	2·43	2·13	1·11	0·84
350	2·97	2·45	2·13	1·15	0·84
400	2·84	2·48	2·16	1·16	0·84
450	2·79	2·47	2·20	1·26	0·84
500	2·90	2·45	2·20	1·45	0·84
550	2·85	2·47	2·20	1·48	0·84
Mean result.	2·89	2·42	2·14	1·18	0·82
Proportional result . .	2·89	2·53	2·17	1·44	0·72

(3) An inspection of the mean results of the above Table, with the added line giving the proportional results, will show how closely these agree with the law that the friction is proportional to the area.

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[1] Paper read before the Manchester Association of Engineers, 1890, p. 129, Table XI.

The vertical columns in this Table also confirm Mr. Tower's experiments in regard to the friction being independent of the load.

TABLE III.—FROM TOWER'S EXPERIMENTS.[1]

Journal 4 inches diameter and 6 inches long; chord of arc of contact, 3·92 inches; load, 100 lbs. per square inch; bath of lard oil.

		Speed in Feet per Minute.							
		105	157	209	262	314	366	419	471
Temp.	Relative Viscosity.	Actual Friction in Lbs. per Square Inch of Nominal Area.							
° F.									
120	35	0·24	0·29	0·35	0·40	0·44	0·47	0·51	0·54
110	40	0·26	0·32	0·39	0·44	0·50	0·55	0·59	0·64
100	48	0·29	0·37	0·45	0·51	0·58	0·65	0·71	0·77
90	55	0·34	0·43	0·52	0·60	0·69	0·77	0·85	0·93
80	65	0·40	0·52	0·63	0·73	0·83	0·93	1·02	1·12
70	75	0·48	0·65	0·80	0·92	1·03	1·15	1·24	1·33
60	89	0·59	0·84	1·03	1·19	1·30	1·40	1·48	1·56

This Table shows how closely actual tests confirm the theory that the resistance is proportional to the viscosity of the lubricant.

(*a*) Reading the columns vertically, the increase in friction is almost directly proportional to the increase in the viscosity of the oil.

(*b*) Reading the lines horizontally, the friction increases with the speed, as already indicated in Table I.

(*c*) The first two columns show how the viscosity falls as the temperature of the oil rises.

CONDITIONS NECESSARY FOR PERFECT LUBRICATION.

Having seen that the results of actual tests confirm the hydrodynamic theory of lubrication, it remains to determine the conditions under which the oil-film is able to support pressure.

It was shown in *Fig. 6* how the pressure is distributed throughout the oil-film in a journal bearing, on the assumption that the surface is flat instead of curved. Leaving the journal bearing with its curved surface, let the simpler conditions of an oil-film enclosed between two plane surfaces be considered, and let the length of such surfaces be defined as the dimension in the direction of motion and the width as the dimension at right angles to it. Four cases will be considered:—

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[1] Tower's Experiments, Inst. Mech. Eng., 1883, expressed in actual friction. Relative viscosity added from Messrs. Archbutt and Deeley's work, "Lubrication and Lubricants." 2nd edition, Table XII. London, 1907.

CASE 1. *Two parallel plane surfaces of infinite extent.*

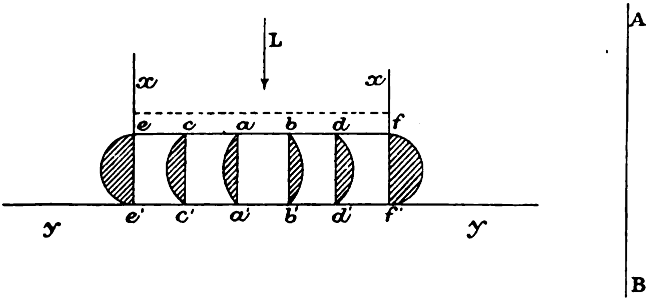
As there are no free edges at which the oil can escape, pressure would be developed in the film if a load were added to the upper plane. If these surfaces were in relative tangential motion, as shown in *Fig. 7*, the volume of oil per unit of area passing any vertical plane $c\,d\,g\,h$ per unit of time would be equal to the contents of the wedge $c\,d\,h\,g\,c'\,d'$, and the volume entering to take its place would be the contents of the wedge $a\,b\,f\,e\,a'\,b'$.

This case does not occur in practice, but it illustrates the flow of oil between two plane surfaces in its simplest form, and shows that the volume of oil entering between any pair of vertical planes at right angles to the direction of motion is equal to the volume leaving, if there is no leakage at the edges of the lubricated surfaces.

CASE 2. *Two parallel planes as before, but one of limited length.*

Let $x\,x$ and $y\,y$ (*Fig. 8*) represent a section through the two planes and let the plane $x\,x$ be of limited length. Assume that there is no tangential motion, but that the planes are being forced together by a load L which is squeezing out the oil. Then, taking vertical planes at $a\,a'$, $b\,b'$, $c\,c'$, $d\,d'$, $e\,e'$, and $f\,f'$, the oil in the section $a\,b$ will be forced to the right and left of the centre-line, as shown by the curved lines, and the hatched areas at $a\,a'$ and $b\,b'$ will

Fig. 8.



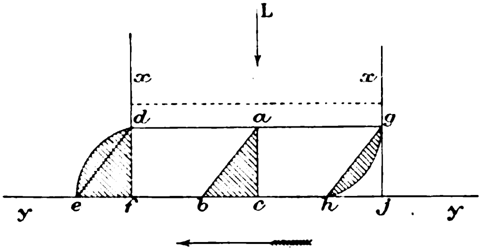
represent the volume passing at these vertical planes. At *c c′* and *d d′* the volumes passing will be increased by that from the section *a b*, and at *e e′* and *f f′* they will be further increased, so that each hatched area will represent the volume of oil passing at that vertical plane.

If AB be taken to represent the centre-line of a shaft, and *x x* to be a collar on that shaft, then the Figure will illustrate also the way in which the oil is squeezed out between the collar and the rubbing surface in a collar thrust bearing.

Case 3. *Two parallel planes as before, one of limited length, under pressure and in tangential motion (Fig. 9).*

Let the planes be as in Case 2, but let the plane *yy* be moving in the direction of the arrow, and assume the vertical movement due to the load to be small as compared with the horizontal. Then at some point at or near the centre of the plane *x x* there will be true viscous flow in the oil-film as in Case 1, and the volume of oil passing the vertical plane *a c* will be proportional to the hatched area *a b c*. To the left the volume leaving and passing the vertical plane *d f* will be increased by the quantity due to the planes *x x* and *y y* slowly approaching each other, and the line *d e* will have a bulge to the left, the volume being represented by the hatched area. To the right the volume entering and passing the vertical plane *g j* is represented by the triangle *g h j*, but this will be reduced by the bulge of the line *h g* to the right, and the volume entering will be reduced to the extent indicated by the hatched area.

Fig. 9.



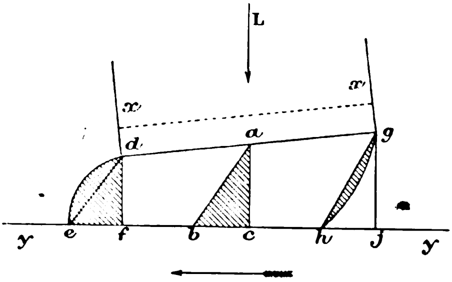
The quantity entering between the surfaces, as represented by the unhatched area *g h g*, is less than the quantity leaving, as represented by the hatched area *d e f*; therefore the planes *x x* and *y y* will come together, and cannot continuously maintain fluid pressure.

CASE 4. *Two planes as before, one of limited length under pressure, and in tangential motion, but not parallel to each other in the direction of motion.* (*Fig. 10.*)

Let the planes be as in Case 3, but let the plane *x x* have a slight inclination to the plane *y y*, with the angle facing the entering oil-film. Then the general condition of flow will be as in Case 3; but if the volume of oil entering, as represented by the unhatched area *g h j*, is not less than the volume passing out, as represented by the hatched area *d e f*, the oil-film will be maintained and will sustain pressure.

This is the condition necessary for perfect lubrication between bearing surfaces. By a slight shifting of the centre of the shaft in relation to the centre of the brass, this inclination of the surfaces may occur in journal bearings, and if oil is supplied at the right point in sufficient quantities these bearings will, as has been shown, run with an extremely low frictional loss and carry heavy bearing-pressures.

Fig. 10.



The necessary inclination of the surfaces is not possible between the rubbing surfaces of thrust bearings of the ordinary types; hence they do not attain to the condition under which perfect lubrication is possible. In the four cases stated above, the surfaces are assumed to be of infinite width, and the mathematical investigation of these conditions for both plane and curved surfaces has been fully explained by Professor Reynolds.

In practice, however, bearings are not of infinite width, and there is leakage of oil at the sides. The amount of this leakage in narrow bearings is relatively large, and it is necessary to take the ratio of length to width into consideration before a rational formula can be arrived at.

Certain improvements in Professor Reynolds's mathematical treatment of the subject were made by Mr. Sommerfeld,[1] and in 1905 Mr. A. G. M. Michell,[2] in Australia, showed how a complete solution of the problem of viscous flow in three dimensions could be arrived at for plane surfaces.

His calculations give the results for four different ratios of length to width, and include:—

(*a*) The necessary angle of inclination of the surfaces.

(*b*) The distribution of oil-pressure throughout the film.

(*c*) The position of the point of resultant pressure.

(*d*) The coefficient of friction.

The following are Mr. Michell's formulas for the friction between perfectly lubricated plane surfaces of different proportions of length to width.

Let c denote the angle of inclination between the surfaces.
λ „ viscosity of the oil in absolute units.
u „ speed of rubbing in centimetres per second.
p „ pressure in dynes per square centimetre.
μ „ coefficient of friction.
$\left.\begin{matrix} k \\ m \end{matrix}\right\}$ „ $\left\{\begin{matrix}\text{constants for the ratio of length to width of the} \\ \text{surfaces.}\end{matrix}\right.$

Then $$c^2 = \frac{k \lambda u}{p}.$$

And $$\mu = c \times m.$$

He determined the following constants and positions of the centre of resultant pressure from the rear edge for surfaces of different ratios of length to width.

			Point of Resultant Pressure.
1. Square surfaces	$k = 0 \cdot 0213$	$m = 10 \cdot 83$	0·42
2. Width one-third of the length.	$k = 0 \cdot 00155$	$m = 143$	0·39
3. Infinite length	$k = 0 \cdot 00258$		
4. Infinite width	$k = 0 \cdot 0506$	$m = 4 \cdot 86$	0·433

In the sense in which it is used above, the coefficient of friction is the ratio of the load to the viscous resistance of the oil-film.

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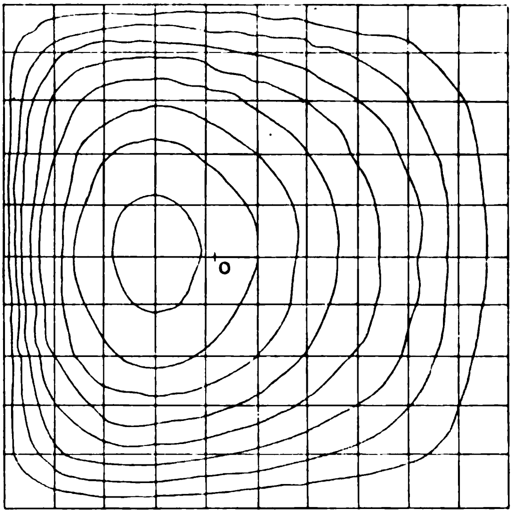
[1] *Zeitschrift für Mathematik und Physik*, vol. 50, pp. 97–155.

[2] *Loc. cit.*, vol. 52, 1905.

This having been found, the heat generated per minute is $\frac{L \mu s}{778}$ B.Th.U., where L denotes the total load in pounds and s the mean rubbing-speed in feet per minute. If this heat is greater than can be dissipated by radiation and conduction, it is necessary to cool the oil.

Fig. 11 shows the distribution of lines of equal pressure in a square block, as calculated from the foregoing formula, and also the point of resultant pressure O for the whole surface. This should be compared with the distribution of oil-pressure in a journal bearing, according to Mr. Tower's experiments (*Fig. 6*).

Fig. 11.



Owing to the extreme smallness of the angle between the planes (about 1/3,000) necessary to maintain pressure in the oil-film, it is not practicable to have them fixed, but if one of the planes is the face of a block pivoted on the line of the resultant of the components of friction and load, passing through the calculated point of resultant pressure in the oil-film, it will assume and maintain the correct inclination automatically.

The point of pivoting may be varied within moderate limits, but at the cost of increasing the friction. Similarly, if the length of the blocks is increased relatively to the width, there is a rapid increase of friction. Referring to the results given above, it may be seen that the relative coefficients of friction for a square block and one of width equal to one-third of the length are 10·83 and 143, i.e., in the ratio of 1 to 13.

The use of plane rectangular surfaces moving continuously in one direction does not occur in machinery, but the conditions necessary for the perfect lubrication of segmental blocks rotating around a common centre must be of a similar nature.

If, therefore, a thrust-bearing is constructed with one plane surface subdivided into radially-arranged segmental blocks, each pivoted at or near its point of resultant oil-pressure and free to move through a slight angle from the plane of rotation, then such a thrust bearing will be the mechanical equivalent of a perfectly-lubricated journal bearing when a sufficient supply of oil is provided. The first thrust bearing of this type was made by Mr. A. G. M. Michell in Australia in 1905, and since then considerable numbers have been made both there and in England.

The load-carrying capacity of these bearings is proportional to the speed and to the viscosity of the lubricant. So that if a given bearing will carry 50 lbs. per square inch at a rubbing-speed of 1 foot per second with an oil of 0·5 viscosity, it will carry 500 lbs. with an oil of 5·0 viscosity at the same speed, or at a speed of 10 feet per second with the same oil.

Such bearings are in use for high speeds in steam-turbines with oil lubrication and for low speeds in grinding machinery with grease lubrication, to cite two extreme examples.

Figs. 12 show a bearing on this principle designed by the Author for Messrs. Belliss and Morcom, of Birmingham, for a steam-turbine.

A is the collar on the shaft.

B are the segmental rubbing-blocks, the backs of which are cut away as shown, to allow of their tipping through the necessary angle to the plane of rotation.

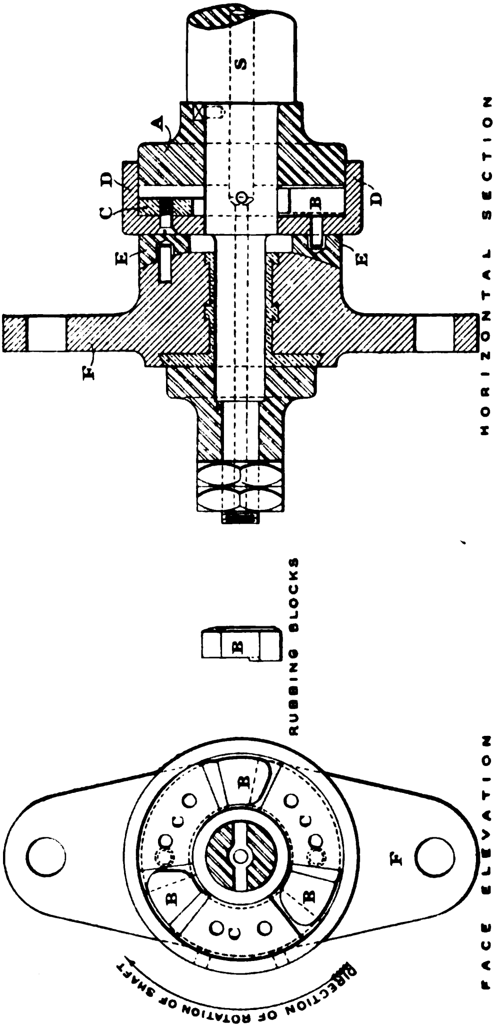
C are spacing-blocks between which the loose rubbing-blocks are fitted.

D is the case holding the spacing- and rubbing-blocks together.

E is a washer, concave on one face and flat on the other, to provide means of automatic adjustment.

F is the cross-piece with a convex face on to which the washer fits, and having holes through which bolts pass to transfer the thrust to the frame of the turbine.

The oil is supplied through a hole in the centre of the shaft S. It should be noticed that, whereas in ordinary collar thrust bearings it is necessary to add a number of collars to the shaft in order to secure sufficient bearing surface, in the Michell bearing one collar is usually more than enough, and to get the best result at high speeds it is advantageous to reduce even this area by introducing spacing-blocks.


HORIZONTAL SECTION
S
A
D
C
B
D'
E
E
F
RUBBING BLOCKS
B
FACE ELEVATION
B
C
C
C
C
B
B
C
F
DIRECTION OF ROTATION OF SHAFT

Figs. 12.

Scale: 3 inches = 1 foot.

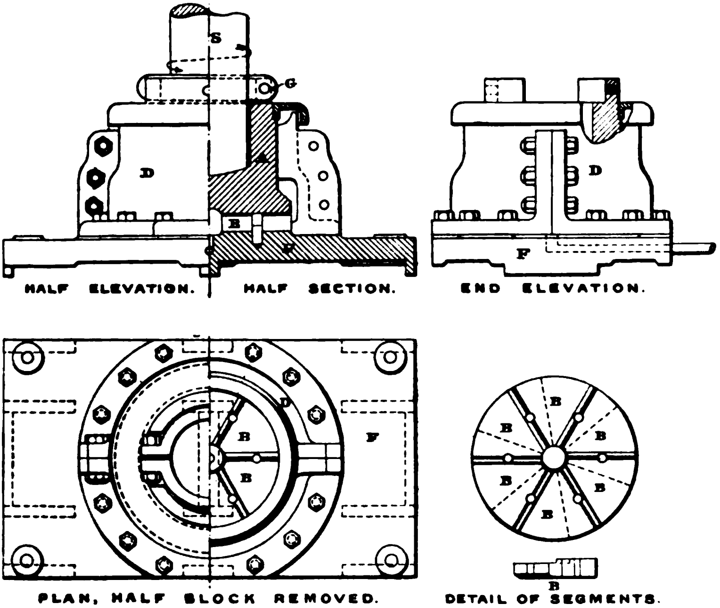
The bearing in question was tested by the Author at Messrs. Belliss and Morcom's works under a total load of 1,500 lbs., or 500 lbs. per square inch, at a speed of 1,750 revolutions per minute, under which conditions it ran continuously at a temperature of

124° F. The absolute viscosity of the oil used was 4·8, which was much too high, and the bearing would probably have run at a lower temperature with a thinner oil. The firm have between seventy and eighty of these bearings in use on steam-turbines at the present time.

Figs. 13 show a low-speed bearing designed by the Author for Messrs. Thos. C. Fawcett, Ltd., of Leeds, for their large pan grinding-mills.

In this there is no spherical adjustment, but the shaft is a loose fit in the shoe-piece A, which is turned by means of a driver (G) attached to the shaft; there are also no spacing-blocks. The essential parts are lettered as before, and the illustration shows the general construction of the bearing.

Figs. 13.



HALF ELEVATION. HALF SECTION. END ELEVATION.

PLAN, HALF BLOCK REMOVED. DETAIL OF SEGMENTS.

Scale : ⅛ inch = 1 foot.

The load is 13 tons, or 350 lbs. per square inch of bearing surface, and the speed 24 revolutions per minute.

Several of these bearings are at work, and Messrs. Fawcett state that the saving over the old footstep bearing effected by their use amounts to 20 to 25 per cent. of the total power required to drive the machine, besides which they find a great saving in the cost of repairs. The lubricant used is 1½ oz. of thick grease per day.

The Author made some tests with an experimental bearing of the Michell type in which he deduced the coefficient of friction from the rate at which the kinetic energy of a fly-wheel was absorbed. The results agreed fairly closely with those obtained by calculation from Mr. Michell's formula for a square block, being 0·004, against 0·00147 by calculation.

The discrepancy arises partly from the fact of the block travelling in a curved path instead of a straight line, but is also due in part to the ratio of length to width of the blocks and to the position of the pivoting point not being theoretically correct. There was an increase of friction as the speed fell below a certain point, similar to that shown by Professor Goodman's tests with a journal bearing.

The friction between two perfectly lubricated surfaces is, as has been shown, proportional to the area in viscous shear. Therefore, in an ordinary collar thrust bearing, in which the safe pressure is only 50 lbs. per square inch, the area, and consequently the actual friction, will be at least ten times as great as in a bearing which will carry safely 500 lbs. per square inch. The conditions necessary for two plane surfaces to maintain high pressures are provided in the Michell thrust bearing, hence the saving in friction.

The Author is indebted to Mr. G. Gerald Stoney, F.R.S., M. Inst. C.E., for going through this Paper and making some valuable suggestions.

The Paper is accompanied by four tracings and eight sketches, from which the Figures in the text have been prepared.

Discussion.

The Chairman The CHAIRMAN, in moving a vote of thanks to the Author, remarked that The Institution was much indebted to him for having brought before it a difficult and complex problem, and for having shown to what extent he and others had solved it by their researches and experiments. He hoped that those who had carried out similar experiments would give the members the benefit of their experience.

Mr. Ellis. Mr. W. H. ELLIS shared the Chairman's view that The Institution had received a contribution of considerable value, which had involved much study and research. It was naturally a difficult subject to discuss in detail, especially for one whose experience of the problem had been rather in the manufacture of large thrust-shafts for marine work than with the question of friction involved in their subsequent use. The Author's investigation would, however, concern the manufacturer, in so far as it tended to do away with the very uneconomical method which involved the removal, in some cases, of 6 to 8 tons from a single shaft in order to make room for the spaces between the collars, the surfaces of which carried the thrust.[1] No doubt the students of the turbine system of propulsion were conscious that in abandoning the reciprocating engine they were at the same time introducing a reciprocal action as between the thrust inwards of the propeller and the blading of the turbine, being of the opposite hand to that of the propeller, thereby balancing to a large extent the thrust of the propeller, and thus greatly simplifying the thrust problem. What would have happened by now with the large horse-powers—as much as 70,000 and 80,000 HP.—in Atlantic liners and warships it was difficult to say, because the problem of the manufacture of large crank-shafts, in itself sufficiently difficult, would often have been much complicated if it had been necessary also to provide for the absorption of the enormous thrust which would have been involved by such horse-powers. That had to some extent been reduced by the reciprocal action of turbines to which he had referred. The Author showed in *Fig. 12* a thrust-bearing he had designed on that principle, and it would be useful if an illustration could be given of the same design applied where the horse-power was so great as to necessitate more than one ring. He hoped the Author would also indicate the dividing line between multiplication of rings and increase in diameter. It appeared to him that on the blocks

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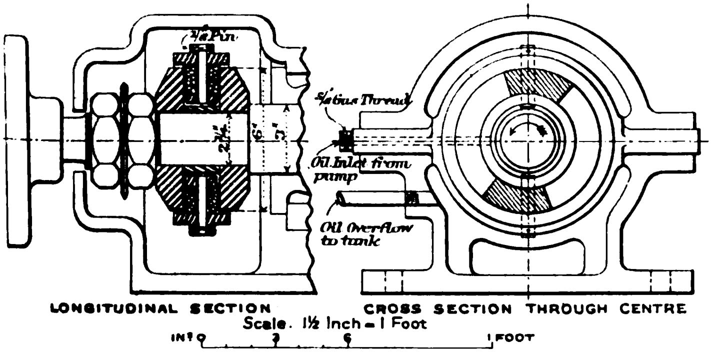
[1] The problem would have become much more acute if turbine propelling-machinery had not been introduced.—W. H. E.

Mr. Ellis. shown there must be a point at which the Author would hesitate to increase the diameter, and would recommend the multiplication of rings, or possibly two or three rings. It would be desirable if the Author could add a few words in further explanation of a point referred to at the top of p. 233, namely, the calculations necessary to determine what proportion would give the balance between the ingoing and the out-going oil. He desired to add, in reference to the balancing action of turbine propelling-machinery, that the problem of the large thrust bearing was to some extent revived by the introduction of the geared turbine. It appeared to him, therefore, that the subject must be one of special interest to marine engineers, if they again had to face the absorption of thrust entirely by thrust bearings, without help from the blading of the turbines.

Capt. Sankey. Captain H. Riall Sankey thought that the Author's reason for writing the Paper, stated in the first paragraph, might have been a little extended. He had shown by *Figs. 8*, *9* and *10* that, in order to obtain a film of oil between two surfaces which were being pressed together, they must be inclined to each other, and further, that in the case of ordinary journals the inclination was obtained automatically by an almost fortuitous arrangement of a slight shifting of the shaft as explained by the Author. A formula was given on p. 241 which related the angle of inclination of the line $d\,g$ in *Fig. 10* to the line $f\,j$, and there were one or two points in connection with that formula to which he desired to call attention. First, although it might be somewhat hypercritical, the Author stated that c denoted the angle of inclination, but it actually denoted the tangent of the angle of inclination, for on p. 242 the Author gave that angle in some cases as being 1/3,000. Bearing in mind that, when the line $d\,g$ was 1 inch, as in the first example given of a bearing made for Messrs. Belliss and Morcom, the difference between the height at one end and at the other was only one-third of the thickness of a piece of cigarette-paper, it was quite obvious it would be impossible to adjust the inclination of the two planes to a sufficient degree of accuracy, and, in fact, this was stated to be the *raison d'être* of the Michell bearing. He did not think, however, the Author had made his case as strong as he might, because that angle depended, as would be seen by the formula on p. 241, on λ, the coefficient of viscosity. Viscosity was there expressed in absolute units; he presumed the Author meant at a temperature of 20° C., or at a temperature of 60° F., according to the units used. As was well known, the coefficient of viscosity varied greatly with the temperature. In the case of the Belliss–Morcom bearing the temperature was stated to be 126° F. He presumed that the temperature of the oil would be slightly more than that, certainly not less. Capt. Sankey. If 4·8, the figure given on p. 245 for the absolute viscosity of the oil, was at 60° F., then at 126° F. it would not be much more than 0·4. Inserting the figure 4·8 in the formula under discussion, c was found to be $\frac{1}{1700}$, but when the viscosity was reduced to 0·4 it became $\frac{1}{6000}$. The point he wished to make was that not only must the inclination between the two surfaces be extraordinarily small, and therefore require extraordinary accuracy in manufacture, but it had to vary from the time the bearing started running, and the slightest alteration would prevent the bearing from running properly: the film of oil would not be obtained which was necessary for "perfect film lubrication." It was obvious there must be some automatic means of adjusting the inclination between those surfaces,

Figs. 14.



and that was precisely what Mr. Michell had provided by using movable disks or plates. He was glad to say he had had an opportunity of using some of those bearings in connection with Marconi discharge disks. These were steel disks a little over 4 feet in diameter, rotating at about 2,600 revolutions per minute, and carrying copper studs; and it was necessary to have a thrust bearing to balance the thrust of the driving machinery. A bearing proposed by the Author was 7 inches over all, having two friction disks placed at opposite diameters. They were each about 2½ square inches in area, and the thrust provided for was 2,000 lbs., or 400 lbs. per square inch. The bearing was slightly different from those described in the Paper, inasmuch as it took the thrust in both directions. As a result, the disk, instead of being pivoted on the back, was pivoted through the centre by means of a bolt, as would be seen from *Figs. 14*, and could therefore adjust itself according to the direction

Capt. Sankey. from which the thrust came. It was stated on p. 230 that the saving in the use of roller and ball bearings was in their low static friction rather than in their low running friction. He had had an opportunity of proving that statement with the Marconi disks to which he had referred. Originally, ball bearings were used for the shaft-bearings, but at the present time plain phosphor-bronze bearings under forced lubrication were running quite satisfactorily, and, as far as he could see, there was no difference in the amount of friction.

Mr. Stoney. Mr. G. GERALD STONEY remarked that thrust bearings such as those referred to in the Paper would make possible a geared turbine ship with each shaft passing perhaps 40,000 HP. The term "coefficient of friction" was frequently used in the Paper. He suggested that "resistance per square inch of projected bearing surface" be substituted. That expression was used in Tables I and III, and if worked out it would be found that in Table II the resistance per square inch, which was the product of the coefficient of friction by the pressure, was practically constant and equal to 0·36. The resistance per square inch was, in a perfectly lubricated bearing, independent of the area and pressure, and for low speeds such as the Author had dealt with it varied directly as the velocity. As the speed increased, according to Mr. Lasche's experiments, carried out on high-speed bearings, the resistance gradually altered until it varied as the square root of the velocity, and finally at high speeds, about 30 feet per second, it was practically independent of the velocity. That meant that the average thickness of the oil-film must be independent of the pressure per square inch; that it thickened as the speed increased; and that at high speeds the thickness of the oil-film was practically proportional to the surface speed of the bearing. The Author stated on p. 243 that the pivoted thrust bearing was the mechanical equivalent of a journal bearing. In a journal bearing the distribution of pressure was as shown in *Fig. 6*, where the centre of pressure was practically the centre of figure. The coefficient of friction was very small, perhaps 1/1,000, in such a bearing; and in a bearing of 4 inches diameter, such as Mr. Tower experimented with, the distance of that centre of pressure from the centre of figure would only be an angle equal to the coefficient of friction. Thus it would be somewhere about 2/1,000 inch from the centre of figure, or practically an inappreciable amount. When the arc of contact was shortened, as given in Professor Goodman's test in Table II, practically the same form of oil-film was obtained as in a pivoted thrust-block. There a wedge action was obtained similar to that in a pivoted thrust-block, and the centre of figure was to all intents and purposes

Mr. Stoney.

the centre of pressure—that was to say, instead of the distribution of pressure being as shown in *Fig. 11*, it was as shown in *Fig. 6*. Experiments further showed that it was practically immaterial where the pivot was put in such a thrust-block; it worked equally well whether it was centrally pivoted, as has been proposed by Sir Charles Parsons, or put out of centre as Mr. Michell did. The whole theory was exceedingly difficult, and he did not think it had yet been properly solved by mathematicians. The pressures that could be worked to were very great; personally he had worked up to 4,000 lbs. per square inch at 52 feet per second, and Mr. Kingsbury in America had reached 7,000 per square inch. At both those pressures the bearing failed, owing to the white-metal squeezing out. The strength of the white-metal limited the pressures that could be used, not failure of the oil-film. It was certain that such bearings could be used up to speeds of 50 or 60 feet per second at 500 lbs. per square inch with a considerable margin of safety. A notable example of such a bearing was in the cross-channel boat "Paris," where there were thrust-blocks on each shaft, with centrally pivoted bearings taking 24 tons each, at about 300 revolutions per minute.

Professor Goodman.

Professor John Goodman thanked the Author for the very clear way in which he had placed the subject before The Institution. It might be of interest to refer briefly to the history of the subject. Some 30 years ago, when Mr. Tower made his experiments, ultra-practical men asked what was the use of making tests on bearings flooded with oil, because in practice no bearings were treated in that manner. But what had been the result? At the present day almost every high-speed engine in the world was fitted with an oil-bath or its equivalent. Mr. Tower's results also led Professor Osborne Reynolds to go very thoroughly into the theory of the subject, and, as was well known, the results of his investigation were in remarkable agreement with the experiments of the former. The latest outcome of that theory was Mr. Michell's work on the thrust bearing. He thought the illustrations given in the Paper were hardly fair to the old thrust bearing. For example, in the bearing illustrated in *Fig. 3* the oil-holes were so arranged that the oil fell on the outside of the collars, whereas it was well known that the oil should be applied to the bottom of the collars. Then by centrifugal force the oil was carried outwards and distributed over the collars themselves, which made a much more satisfactory bearing. Again, the ordinary pivot or thrust bearing for high speeds was always fitted with loose collars at the bottom, and the oil was supplied through the middle of the collars. He had himself made bearings of that type and tested them up to 340 lbs. per

Professor Goodman. square inch, and had not experienced the slightest difficulty in keeping them cool. He did not know exactly what the coefficient of friction was, because it was a rather difficult matter to determine it in a bearing of that type. Coulomb's laws of friction were known to be very inaccurate, largely due to the fact that his experiments were made on a toy scale; and when similar tests were carried out on a larger scale, totally different results were obtained. The friction was not independent of the speed; with dry surfaces it fell off rapidly with the speed. It was not independent of the area; it fell off somewhat rapidly as the area was decreased. It was not proportional to the force pressing the two surfaces together; it fell off somewhat rapidly. It was, however, tolerably true that it was dependent only on the nature of the surfaces. He thought it was important to call attention to that point, because many blunders had arisen from the assumption that the Coulomb laws were correct. The Author referred on p. 226 to the coefficient of friction between smooth dry surfaces of anti-friction white-metals, but surely a bearing was never intended to run dry. The coefficients obtained, even with a very slightly greasy shaft, were much lower—somewhere in the neighbourhood of one-tenth of the values given by the Author. Professor Goodman was still of opinion that the ball bearing could compete successfully with a bearing of the type described in the Paper. He had seen many failures of ball bearings, but he believed their failure in every instance had been due to bad design. He further believed that the coefficient of friction with a well-designed ball bearing would be lower than with a bearing of the Michell type, although he was perfectly willing to admit that in some cases a bearing of the latter type would be better suited to the work than a bearing of the former type. Captain Sankey had referred to a ball bearing which had been replaced by a phosphor-bronze bearing, and it would be interesting to have particulars of the ball bearing which failed. About 13 years ago some very careful experiments were made to investigate the manner in which a bearing wore. It was found that when the brass subtended about 180° the wear was always on the "off" side, exactly as would be expected from Mr. Tower's experiments. The angle embraced was then reduced step by step, and it was still found that the wear occurred on the "off" side of the brass. When the brass subtended about 90°, however, the wear was equal on both sides. With less than about 90° the wear took place on the "on" side of the brass and not on the "off" side. A narrow brass such as that was very similar to the block used in the Michell bearing. He was not prepared to say that the Michell theory was wrong; but it was curious that in the case of a

Professor Goodman.

brass subtending only a very small arc the wear should be on the "on" side, and not on the "off" side, as would be expected from that theory. It was an interesting point that might well be gone into somewhat more fully. He had observed it many times since in other experiments, and was therefore quite sure it was the case. It would be a great convenience if the Author in his reply would give the viscosity in English units, as it was confusing to have the C.G.S. system on one line and the British system on the next. No one admired Mr. Tower's work more than he did, but it was to be regretted that Mr. Tower had no artificial means of keeping his bearing at a constant temperature; hence all his results obtained were more or less defective, because the temperature of the bearing and of the oil varied from time to time. It was given as 90°, or 100°, or 120°, but as a matter of fact it varied considerably during the tests. He did not make that statement without having definite proof; moreover, there was internal evidence that the temperature of the film did vary, and that had been pointed out by Professor Osborne Reynolds. He believed that Mr. Lasche's experiments, in which it appeared that the friction remained constant at very high speeds as the speed increased, were to a certain extent open to the same objection as Mr. Tower's. He was well aware that Mr. Lasche used some means of keeping his bearing at constant temperature, but he could not believe that the temperature was actually kept constant. Very shortly after Mr. Lasche's experiments were published, Professor Goodman to a large extent repeated them, and, although he could not get up to the same speeds, he found very definitely, as the theory would indicate, that the friction increased directly as the speed, even up to the highest speed to which he could attain—of course not including the irregularities which always occurred at low speeds.

Capt. Sankey.

Captain H. Riall Sankey desired to say, in answer to Professor Goodman's question, that the ball bearing to which he had referred did not fail in the ordinary sense, but owing to high-frequency currents a certain amount of electrolytic action took place which pitted the balls. The failure, therefore, had nothing to do with the ball bearings as such.

Mr. Ferranti.

Mr. S. Z. de Ferranti had been interested for some years in trying to obtain an end thrust-bearing which would carry very heavy loads efficiently at high speeds, namely, the speeds of reaction turbines. The loads which he wished it to carry were very considerable, and he made a number of experiments with a view to taking those loads by different kinds of thrust bearings instead of by a dummy piston. In one case, 80 tons had to be carried con-

Mr. Ferranti. tinuously at 1,500 revolutions. His experiments had led him to conclude that, with the means available, he could not carry that load on a single collar, and that it was necessary to have a multiple collar somewhat of the nature of the old marine thrust bearing. As a matter of fact, he used in that case ten rings, and worked up to a pressure of about 500 lbs. per square inch. The lubrication was arranged in the ordinary way, just as for the ordinary bearings of a turbine—that was, the oil was cooled artificially, and was supplied at a moderate pressure by a pump. It appeared to him that the vital point with such high pressures was to make sure, where the collars were multiple, that an approximately even load was obtained on each of the collars, or, rather, that no collar had more than its proper load on its surface. He had tried to devise all sorts of lever arrangements for equalizing the load between the collars, and eventually he had arrived at a simple spring support so arranged that, if more than the correct load came on any one collar, it collapsed a few thousandths of an inch and equalized the loads on the others. The result was that, notwithstanding the stretch of the shaft holding the collars (for they could only be of a moderate diameter), the collapse of the box that held the standing collars, and inaccuracies of workmanship and fitting, there was still an even distribution of the load between the various surfaces, and the thrust worked well in consequence. The Author had put before the members the scientific side of the working of thrust bearings. Unfortunately, more invention was often necessary for the production of those scientific explanations than was required in the development and building up of the original invention. He did not wish to go quite as far as that in the present case; but some of the opinions that had been expressed did not fit in very well. In dealing with the delicate question of getting the right amount of angling on the two surfaces on which it was necessary to take in the oil, he took a ring surface just like an ordinary marine thrust ring, but continuous all round instead of being half a circle, and grooved it deeply with grooves about $\frac{1}{4}$ inch wide. That made a number of segmental surfaces on which the load was carried. The edges of the surfaces were rounded where the oil had to enter, so that it would not be scraped off, and the surfaces were bevelled off to the extent of about the thickness of a piece of cigarette-paper. He made very careful experiments because he had two thrust collars being pressed up against a running collar, and that formed a very good brake. He was thus able to weigh very accurately the friction resulting from any particular load, and to observe the quality and temperature of the oil, and other conditions. In the result he found he could

Mr. Ferranti.

readily vary the angle which the Author had calculated theoretically. The essential thing was to round the edges, and it was necessary to shorten the length of the surface in the direction of motion—that was, round the circle in that case, and to make the length of the individual surface small. It did not matter exactly what it was, but it had to be small to ensure good results. Under those conditions satisfactory results in working were secured. He obtained coefficients of friction as low as the best that had been referred to that evening; in fact, a non-pivoted, or plane surface cut up by oil-ways worked perfectly well, provided pains were not taken to rub the oil off the surface. In engineering work one of the most difficult problems he had had to face was to prevent oil from getting where it was not wanted. When the way in which the surfaces obtained oil by passing the grooves at very short intervals was borne in mind, it was not at all surprising the method worked perfectly well. He worked up to pressures of only 1,000 lbs. per square inch because he was afraid of his white-metal surfaces. The white-metal surfaces did not actually fail, but he was expecting them to do so. The oil, as Mr. Stoney had said, never failed. The problem was one of getting a non-seizing metal surface opposing a steel surface which would not collapse or crumble away. Then, if the pressures were distributed between the various collars, so that an excessive pressure was not obtained, and the heat generated was taken off, a thrust could be produced which would carry any amount of load.

Mr. Broom.

Mr. H. S. Broom was of opinion that the Author had underestimated the difficulty of securing perfect lubrication with a journal bearing. This could only be obtained with bath or forced lubrication, and in a bearing subject to reciprocating motion the $\frac{3}{1000}$ to $\frac{5}{1000}$ inch clearance required for perfect lubrication would cause a knock which, when started, would prevent an oil-film being obtained between the two surfaces. Mr. Michell had lately applied the tipping-block principle to journal bearings for turbines, reducing the width of the bearing by two-thirds, and as the friction absorbed by the bearing was proportionate to its surface, a great saving in friction in the overall length of the machines was effected and the oil-temperature was reduced. The length of bearings fitted to turbines, which was one source of difficulty in obtaining perfect lubrication, might be reduced by this method. Michell thrust bearings had been tested to a pressure of 12,000 lbs. per square inch without failure of the oil-film. He believed the reason for the lower coefficient of friction in a Michell bearing was that it could be bedded up to surface-plate with a much closer approach to a perfectly flat

Mr. Broom. surface than with a journal bearing bedded to the more or less irregular surface of the shaft. With both high speeds and heavy loads, the Michell bearing possessed great advantages over the ball bearing, as at high speeds the centrifugal action threw the balls on the outer side of the race, and with heavy loads and low speeds the period of compression of the ball bearing was long enough to destroy the molecular construction of the material. After constructing numerous bearings, he had found that the most satisfactory manner of carrying these was with the two blocks carried in a half gimbal, ensuring both blocks taking equal care of the load. Where the surfaces between the rubbing parts were well finished and the materials suitable to the loads, the bearings never failed. The most suitable materials for high speeds were case-hardened steel and a special close-grained mixture of cast iron, not white-metal as suggested. Cast iron apparently held a film of oil better than any other material when standing under load, and no wear occurred before a speed of 10 feet per minute was attained—the starting point of perfect lubrication. The most satisfactory arrangement for lubrication at high speeds was to core the housing of the bearing so as to allow the thrust-block to act as a propeller pumping the oil round to the centre of the bearing.

The Author. The AUTHOR, in reply, said it was quite practicable to design a multiple-collar thrust bearing with pivoted segmental blocks provided with means for distributing the load equally among them, but there had been no difficulty in dealing with any load carried so far on a single collar. Bearings of this type had been made in America over 4 feet in diameter carrying 240 tons. As to the point of pivoting, in a journal bearing, owing to the surfaces being curved and to there being a slight difference between the radius of the shaft and that of the brass, the thickness of the oil-pressure film increased somewhat on leaving the point of nearest approach to the shaft; therefore the oil-pressure figure was almost symmetrical and the centre of resultant pressure was practically in the centre-line of the bearing, as pointed out by Mr. Stoney; but in the case of plane surfaces the greatest pressure was much nearer the "off" side, as was also the point of resultant pressure at which it should be pivoted. He had made some tests as to the effect of varying the pivoting point, in conjunction with Messrs. Belliss and Morcom, in June, 1910. With the block pivoted $\frac{1}{16}$ inch in front of the centre, the temperature was 135° F.; pivoted at the centre, 132° F.; pivoted $\frac{1}{16}$ inch behind the centre, 126° F.; and pivoted $\frac{1}{8}$ inch behind the centre, which was about the theoretical point, 124° F. There was a difference in temperature, and consequently

The Author. a corresponding fall in friction, amounting to 11°, due to the correct pivoting of the block. The blocks were tested by means of a thermometer in the blocks themselves—that was, a hole was drilled in the block so that the actual temperature was obtained as near the face as possible. The bearing was running at 1,750 revolutions per minute, and the load on the blocks was 500 lbs. per square inch. The explanation of a block pivoted in front of the theoretical point working at all was probably that the rise in temperature in the oil-film passing under the block reduced its viscosity and thereby its ability to support the trailing edge. In the large bearings made in America the blocks were approximately square and pivoted behind the centre, so that practical experience there appeared to confirm the correctness of Mr. Michell's theory. These bearings had been tested by the Westinghouse Company to 10,000 lbs. per square inch, at which pressure they ran cool but failed by the white-metal flowing. In reply to Captain Sankey, the viscosity of the oil must be taken at the working temperature. In the case of the Belliss–Morcom tests the viscosity given was at the working temperature and was taken from the absolute-viscosity curve of the oil. With reference to the question of dividing a plane rubbing-surface into a number of fixed instead of pivoted planes. It was quite possible to get an oil-pressure film between the surfaces in this way; there was, however, the objection that the small amount of inclination necessary was apt to wear off. Coulomb's laws had been referred to. The figures given in the Paper had been obtained from Messrs. Archbutt and Deeley's work on Lubrication, and he was not responsible for them. For the mathematics of the flow of viscous substances, alluded to by Mr. Ellis and others, he would refer to Professor Osborne Reynolds's Paper,[1] which went into the subject very fully. The inclination of the blocks was given by him as 2·2 : 1, at the "on" side and "off" side respectively, to get the best results. [The Author here exhibited a bearing which had been running at 1,500 revolutions per minute carrying a load of 1,200 lbs.]

Correspondence.

Mr. Gibson. Mr. J. **Hamilton Gibson** observed that the inefficiency of the ordinary marine type of thrust-block had been forced upon the notice of the engineering world by the introduction of geared

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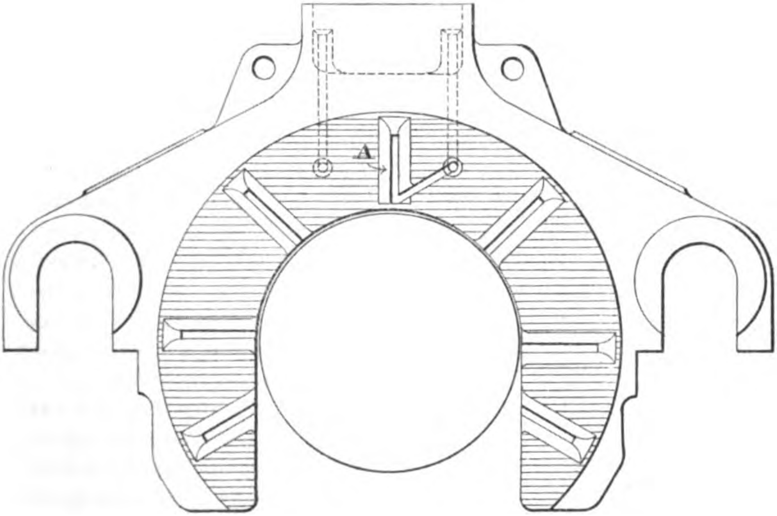
[1] Phil. Trans. R. Soc., vol. 177, p. 157.

Mr. Gibson. turbines for ship-propulsion. The Birkenhead Engineering and Shipbuilding Works, with which he was associated, had completed, early in 1913, a geared turbine steamer of 8,000 shaft HP. for cross-channel service, and had fitted thrust-blocks of the usual horseshoe type, with ample surface for reciprocating engines of equivalent power. The rings were water-cooled, and were lubricated by means of oil-boxes cast on top of the rings. Sinuous oil-grooves were cut in the white-metal faces, and the surfaces were fitted with the usual care bestowed on this type of thrust-block. Trouble was experienced owing to the undue heating of the lubricant and the rapid wear of the white-metal, which dragged over and practically obliterated the oil-grooves. The grooves were increased in number and were deepened, and overhead oil-boxes were fitted on the bulkhead, giving a head of about 14 feet. The oil was, however, "pumped" up through the pipes and displaced the worsted siphons. Wood plugs were fitted into the siphon tubes; but even these were driven out by the back-pressure of the oil. The vessel was only kept in service by constant attention to the thrusts, and it was evident that an entirely different system of lubrication was required to meet the case. Some natural law was being opposed, and it was useless to attempt coercion. It occurred to him that if only the oil could be introduced to and insinuated between the surfaces, as in the case of a main-shaft bearing with oil-wells at the sides, all might be well. Accordingly one set of rings was drawn and wide oil-wells were cut radially across the white-metal. These oil-wells were about 1½ inch wide, and their sides were gently chamfered away to join the bearing surface (*Fig. 15*). It would be seen that the thrust surface was considerably reduced; but the result was perfectly satisfactory. The bearing picked up its lubricant automatically from the oil-bath, and ran without any appreciable rise of temperature. The other thrust was altered in a similar manner as soon as convenient, and the overhead oil-boxes were removed. What had been effected would be readily appreciated. An elementary form of Michell thrust bearing had been made, although he was sure the Author would exonerate him from any charge of attempting to infringe a patent. As a matter of fact, he was so convinced of the superiority of the Michell thrust bearing that he was at present making four thrust-blocks of that type for two twin-screw geared-turbine steamers, each of 5,000 shaft HP., which would be running their trials in the Mersey shortly. The necessary abandonment of the old marine thrust-block for geared turbines appeared to be due to the constant steady pressure between the thrust-surfaces caused by the uniform torque of turbine-driven shafting. In reciprocating

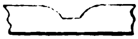
Mr. Gibson.

machinery the thrust varied or pulsated with the impulses produced by the irregular turning-moment of the engines, and consequently the lubricant had some chance of getting in between the thrust-surfaces. But with geared turbine machinery there was no relief once the surfaces came into contact, and the surfaces could not be separated except by some system of forced lubrication where the oil must be introduced at a greater pressure than the unit pressure produced by the thrust. The Michell thrust bearing, however, overcame the difficulty in an extremely ingenious manner, not by coercion, but by persuasion, and Mr. Gibson heartily thanked the Author for his clear statement of the laws governing this most interesting engineering problem.

Fig. 15.



SKETCH SHOWING OIL GROOVES IN THRUST SHOES



SECTION THROUGH OIL-GROOVE A

Mr. Kingsbury.

Mr. Albert Kingsbury, of Pittsburg, Pa., confirmed the experience of the Author as to the effectiveness of thrust bearings of the pivoted segmental type. The first bearing built by Mr. Kingsbury on this principle was made in 1898 and was tested at that time under varying loads up to 5,000 lbs. per square inch

Mr. Kingsbury. with very satisfactory results. Other bearings were built and tested experimentally later on, the results tending to confirm those of his first experiments. At the present time there were a large number of these in service in the United States. The largest of them were those at the Keokuk plant of the Mississippi River Power Company, the diameter of the bearings being 56 inches, the loads 560,000 lbs. to 575,000 lbs., the normal speed 57·8 revolutions per minute and the maximum speed about 100 revolutions per minute. He had but recently received a copy of Mr. Michell's Paper, referred to on p. 241, and therefore could not speak with confidence with regard to the results of his analysis. It appeared to him, however, that the figures for the relative coefficients of friction for the square block and one of width equal to one-third of the length must be somewhat in error. Bearings constructed in approximately the two given proportions did not behave very differently in service; at least, the ratio of 13 to 1 in the friction did not appear to exist. In most of the bearings designed by Mr. Kingsbury the ratio of length to width of the blocks ranged between 1:1 and 1·5:1. As far as he had been able to obtain reasonably satisfactory data, it did not appear that the friction with these blocks was as much as double that calculated on the assumption of absence of leakage at the sides. There was, however, room for more exact experimental investigation in this respect. A curious result which he had obtained experimentally was that when the blocks were supported at the centre, the load-carrying capacity was fully as great as when they were supported at the theoretically best point, provided that the heat due to friction was dissipated. With the central support, however, the friction was much greater than with the eccentric support. A further conclusion reached by analysis was that the point of support giving minimum friction was not the same as that for the maximum load-carrying capacity, but was somewhat farther away from the centre. The point of support, however, could be moved somewhat from the theoretically best point in either case without greatly affecting the operation.

Mr. Lasche. Mr. O. **Lasche**, of Berlin, agreed generally with the theory developed in the Paper, but wished to draw attention to the fact that it was not impossible to design also a solid type of thrust bearing to carry safely specific loads as high as those given on the examples of the Michell type. That would mean, of course, that they must work under similar high efficiency, otherwise they would develop undue heat. For examples he would refer to the work on Turbines for Ships, sect. 115, pp. 217–222, published by

Dr. Bauer and himself.[1] On page 222 of that work data were given Mr. Lasche. for a thrust bearing with the annular type of thrust-block (Fig. 136). The maximum load which one ring could carry continuously at 900 revolutions per minute (42 feet per second circumferential speed) was 15 metric tons, or about 560 lbs. per square inch, with oil at a temperature of 97° C. By testing thrust-collars and blocks of the horseshoe type shown in Fig. 134 (on page 222 an erroneous reference was made to Figs. 136 and 137), it was found that one thrust-block was able to carry at 310 revolutions per minute (16·7 feet per second circumferential speed) more than 30 metric tons, or about 580 lbs. per square inch. While in the first case the load mentioned was the highest limit that could be maintained without exceeding the allowable temperature, in the second case the load was limited by mechanical stresses. At 30 tons, by means of inside water-cooling of the thrust-block and the circulation of 12 litres of oil per minute, the temperature of the oil leaving the thrust-block was only between 40° and 41°, and the sliding faces remained in perfect order. Considering the frictional conditions, there was no doubt that in this case the load could have been forced even higher. With regard to the special means by which it was possible to run the bearings under such high loads, it might be mentioned, as shown in Figs. 134 and 137, that the revolving thrust-collars, and not the thrust-block, were provided with oil-grooves. They were well rounded towards the sliding faces, thus forcing the oil between them.

Mr. Robert Matthews observed, with reference to *Figs. 12*, Mr. Matthews. which showed a spherical annular ring E, bearing on the spherical portion of the cross piece F, to compensate for any inaccuracy or want of alignment, that if this were desirable, then in his opinion for a correct bearing the adjusting washer next to the nuts should also have spherical contact with F, and the brass bushes or steps ought to have a spherical centre-piece, to give freedom of movement, in which case it would be necessary to make the cross piece in two parts. It appeared to him that the two tie-bolts attaching F to the turbine would not be equally loaded and would tend to bend the spindle unless the bearing was made as suggested, or unless everything was always absolutely true. There seemed to be no good reason for limiting the rubbing-blocks B to three in number, especially when there was ample room for six of them, which would adjust themselves automatically into three pairs and thus reduce the pressure on each. It would be interesting to know if the designer had tried the rubbing-pieces B as plain disks

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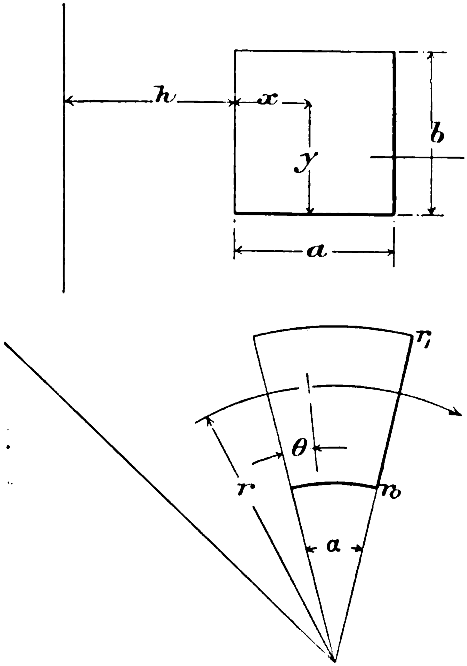
[1] Bauer and Lasche, *Schiffsturbinen*, 2nd ed.

Mr. Matthews. held in place by a hollow round pin or axle through the centre through which the oil was forced, and if so, with what results. That seemed to indicate a cheaper mode of production, and owing to the varying speed of rotation of the collar the six small disks would tend to wear themselves true, being free to turn on their axles.

Mr. Michell. Mr. A. G. M. Michell pointed out that the results derived from the theoretical treatment of rectangular bearing-blocks (such as the formulas on page 241 and *Fig. 11*) might be made available as approximations in the more useful case of segmental thrust-blocks, by a suitable transformation. In effect, the segmental block might be regarded as a map-projection of the rectangular block, according to the following laws:—

Figs. 16.



1. To the point (*Figs. 16*), having the rectangular co-ordinates x, y in the rectangular block whose sides were a and b (x and a being measured in the direction of motion), corresponded a point in the segmental block having the polar co-ordinates

$$r = r_0\, e\, \frac{\alpha y}{a},$$

and $$\theta = \frac{\alpha x}{a},$$

α being the angle between the front and rear edges of the block.

2. The thickness of the oil-film at the point x, y of the rectangular block being $c(h + x)$, that of the film at the corresponding point, r, θ, of the segmental block was $c\, r \sin\left(\theta + \frac{\alpha h}{a}\right)$, the face of the block intersecting the plane face of the other bearing surface on the radial line $\theta = -\frac{\alpha h}{a}$.

These conditions being observed, and the angles α and $\frac{\alpha h}{a}$ being

Mr. Michell.

not too large, the oil-pressure at each point of the segmental block rotating with angular velocity w, would be, to a first approximation, the same as at the corresponding point in the rectangular block, the velocity of the latter being taken as $\frac{w\,a}{a}$. It resulted that, contrary to what might appear at first sight, the inner and outer portions of the segmental block were equally effective in generating oil-pressure, and both carried their full shares of the load. The approximate distribution of pressure in the segmental block being determined as above, it was easy to find the centre of pressure and to assign the theoretically correct position of the supporting point, and to deduce other properties for the purposes of design. Tests recently made on segmental blocks designed by the method just outlined, had shown a satisfactory correspondence with theoretical results. The leading dimensions of a bearing used in these tests were:—

Diameter of thrust-collar	6 inches
Number of pivoted blocks	2
Area of bearing-surface of each block	4·05 square inches
Approximate distance of the centre of the bearing-surface from the axis of rotation (varied, however, slightly in different tests)	2·16 inches
External radiating surface of the bearing (air-cooled in all cases), about	2 square feet.

The pivots of the blocks were approximately $\frac{1}{8}$ inch behind the centres of the bearing-surfaces, and nearly in the position corresponding with *Fig. 11* (p. 242). The bearing was driven by a small electric motor, of which the output was determined under the various conditions of the experiments. Some results of the experiments were given in the following Table:—

Revolutions per Minute.	Total Load.	Intensity of Load.	Kind of Oil.	Viscosity of Oil C.G.S. at 60° F.	Temperature of Oil in Bearing.		Power Absorbed.	Coefficient of Friction.
					°F.	°C.		
	Lbs.	Lbs. per Sq. In.					HP.	
508	3,000	370	Petroleum	0·017	72	22·2	0·049	0·00096
418	10,000	1,235	Mineral colza	0·08	71	21·7	0·137	0·00095
525	5,000	617	Mineral colza	0·08	74	23·3	0·075	0·00084
1,350	5,000	617	Mineral colza	0·08	115	46·1	0·372	0·00161
744	5,000	617	Red mineral	1·08	114	45·6	0·164	0·0014
744	10,000	1,235	Red mineral	1·08	116	157·8	0·228	0·00096

Mr. Michell. In the foregoing results the diminution of the coefficient of friction with increase of load, decrease of speed and decrease of

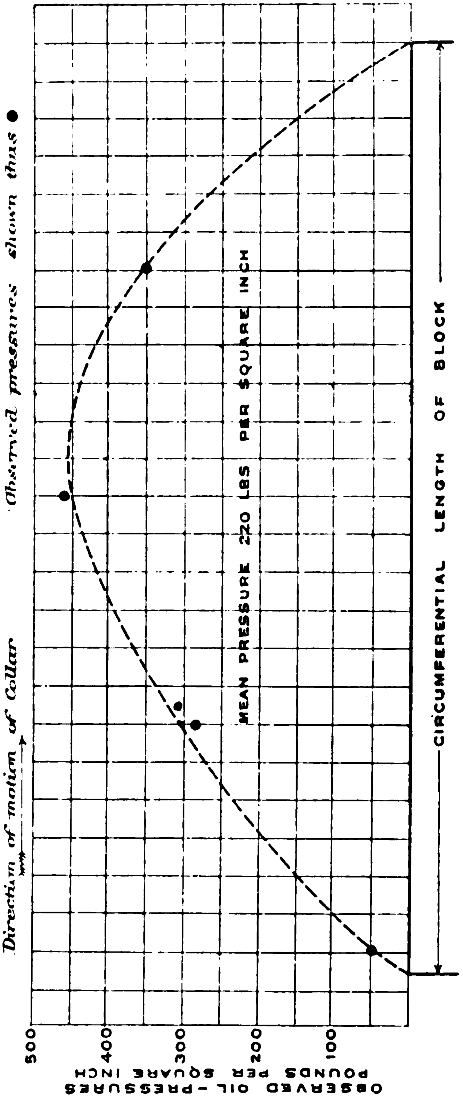


Fig. 17.

viscosity were clearly apparent, and the experimental values of the coefficient approached fairly closely to the theoretical values calcu-

Mr. Michell. lated by the process described. In other experiments on thrust-blocks of the same size pressure-tubes were used, on the lines of Mr. Beauchamp Tower's experiments. *Fig. 17* showed one of the curves of pressure obtained, the pivot of the block being situated at 0·42 of the length from the rear end, as indicated by theory. The effect on the curves of pressure due to varying the position of the pivot was also examined, and it was found that a definite distribution of pressure only occurred when the pivot was behind the centre of the block, as indicated by the theory. In some cases, however, lower and irregular pressure-readings were obtained with the pivot at, or in front of, the centre of the block when the block was not rigid or its face not truly plane. It was evident that in such cases pressures might be generated under portions of the blocks which happened to form suitably inclined surfaces, and it was doubtless the undesigned formation of such surfaces on portions of the working-faces which enabled ordinary non-pivoted bearings to operate at all.

The Author. The AUTHOR, in reply to Mr. Kingsbury, said Mr. Michell's statement, that the coefficient of friction in a block three times its breadth long was thirteen times that in a square block, was based on theory only, and was made on the assumption that the angle between the surfaces remained constant. If the angle were increased the pressure must be reduced, and it was more convenient to assume a constant angle than a constant pressure. The actual friction in the longer block might not be so much higher, but the oil-film would carry less pressure owing to the leakage at its sides. In reply to Mr. Matthews, the cross piece F in the bearing shown by *Figs. 12* was set to suit its journal bearing. The case D was adjusted by the ring E moving eccentrically to the shaft S. The object of limiting the number of blocks in this case had been to reduce the friction, which was proportional to the area of the rubbing surfaces. It would not be advisable to drill holes in the centre of the blocks in the manner suggested, as the oil-film was at its highest pressure there and the hole would allow it to escape. The bearing generated and maintained its own oil-pressure: no forced lubrication was required.

(*Paper No. 3875.*)

"Durban Harbour, South Africa."

By CATHCART WILLIAM METHVEN, M. Inst. C.E.

Author's Reply to the Correspondence.[1]

The Author. THE AUTHOR believed that had Mr. Adam possessed fuller knowledge of all the circumstances, he would not have suggested an entrance through the root of "the Point" near Rutherford Street. But it was perhaps sufficient to point out that as the entrance-works had been commenced before the Author took charge, no change of site for the entrance was possible; and the differences which supervened as to the engineering policy to be pursued arose chiefly out of the questions as to the relative lengths of the works, and the utilization of the tidal scour from the bay. Mr. Adam also underrated the exposure; a mere rubble work such as he suggested would not have withstood the assaults of the seas. An early work in rubble at the end of the Bluff, commenced under the advice of the late Mr. Abernethy, was completely demolished. Like Mr. Adam, the Author preferred a vertical face for quay-walls. The batter given at first to the quay-walls was, however, only slight. No inconvenience whatever arose from it, and floating fenders were used. The system of sheds with raised platforms had proved completely successful. There was free access for trucking between the ship's side and the sheds, and over this space the cranes landed goods on to the shed-platforms, from which they could be either wheeled in to the sheds or loaded on to trucks at shed-floor level, while trollies for goods to town could back in at the rear of the shed and load or unload goods at shed-floor level; or a line of trucks under cover could be similarly loaded or unloaded. There was a minimum of handling, and the system, which was introduced by the Author in 1889, although condemned before it was tried, had been followed in all the many subsequent

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[1] The Paper and the discussion were printed in Vol. cxciii, and the references are to the pages and plates of that volume. The late receipt of this reply is due to the Author's residence abroad.—SEC. INST. C.E.

The Author.

sheds at the harbour. He had not seen any better arrangement in the many harbours he had visited in Europe. Durban Harbour was in fact noted for its dispatch in the handling of goods. Cross-over roads between the sheds were of great importance.

Mr. Barnes's "full inner knowledge of all the proposals for the improvement of the bar and harbour from 1880 to 1909" was not communicated to him by the Author, of whose views he appeared to know very little. The Author's views on the utilization of tidal scour had been grossly misrepresented in certain quarters at Durban, causing much misconception and acrimony, in spite of all the Author could write and say. In his annual report to the Harbour Board for 1892 he said:—

> "The time to dredge will be when this can be done to assist Nature, by being carried out on the same line, or nearly so, that the tides will follow when properly trained and controlled by the works, in a direction as nearly as possible coincident with that of the resultant of the various forces at work."

A recommendation that recourse to systematic dredging should be deferred was adopted by the Legislative Assembly, and the channel was maintained with a loss of only 4 inches in 1893 to 1 foot 7 inches in 1895, thus showing that while the unaided scour was effective to this extent, the overlap of the breakwater of 675 feet was still too great. The average depth on the bar for 1882, and previous years, was about 6 feet at low water of spring-tides, and sometimes a good deal less. In 1892 this depth had been increased, as would be seen from the Table on p. 19, to 13 feet 8 inches, and seeing that practically no dredging had been done on the bar up to that date, if it was not induced scour which effected the improvement, it would be interesting to know what it was. The Author never expected or maintained that tidal scour, by itself, would remove the bar. In his annual report for 1893 he said, referring to misrepresentation of his views:—

> "There are no two . . . schemes before the public, and never have been. If it be represented that my plan is for North and South Pier extension, coupled with whatever dredging may prove necessary, or, shortly, for tidal scour coupled with dredging, versus a proposition to neglect the available tidal scour and to substitute dredging alone for works, then the matter will be properly represented."

Moreover, when requested in 1893 to put in writing the depth he thought might be obtained by the aid of tidal scour, without dredging, he put it at about 18 to 20 feet at low water, if his scheme were carried out in its entirety; and Mr. Barnes himself suggested that the scour might be effective in producing a depth of 18 to 19 feet. Such a depth would, of course, have been quite

The Author. inadequate for a modern harbour, and the Author relied on dredging for anything beyond it. There was no foundation, therefore, for the statement that the Author continued to attribute an undue share of the accomplished success of 36 feet at low water to the effect of scour. This remarkable improvement was due to the use of powerful dredging-plant combined with the proper concentration of the tidal scour from the bay by the extension of the north pier. Before this, any dredging in the direct line of the channel would have been in opposition to the work of the tides flowing in and out round the head of the shorter work on the north side of the channel. There would have been in fact two channels with no stability, and every storm would have undone the work of the dredgers to a serious extent. The advance of the bar seaward had nothing to do with the extension of the north pier. It was clear from Fig. 9, Plate 1, that that advance was due solely to the extension of the south breakwater beyond the north pier, and to the depositing-area thus formed under its lee. With regard to dredging in the Mersey, he had not been aware until now of Mr. Barnes's communication with the Chairman of the Board. But on the 23rd November, 1893, he himself, in support of his views, wrote a full report to the Harbour Board bringing this very important instance of open-sea dredging to their notice, with a Paper on the subject by the engineer, Mr. A. G. Lyster, which had been published in the Proceedings of the International Maritime Congress held in London in that year. As to carrying out dredging by contract, he reported to the Board in July, 1892, that when it became advisable to resort to dredging-operations he would be able to carry them out without assistance from outside; and that, in his opinion, it would be difficult to name any work which, if undertaken by contract, would be more likely to lead to trouble and litigation than a contract to dredge on the bar.

Mr. Bell had raised an important point in his reference to the fact that at 2,500 feet seaward of the end of the present works a depth of only 36 to 39 feet was found at low water, whereas at that distance seaward of the end of the works in 1885 (Fig. 3, Plate 1) the depth was fully 42 feet. The fathom-lines shown in Fig. 3 were, however, the depths in 1887—being the nearest obtainable. The works in that year were somewhat further advanced than in 1885, as shown on the diagram, so that the 7-fathom line in 1887 was only about 2,000 feet ahead of the end of the south breakwater at that time. The diagram referred to by Mr. Bell in the Author's former Paper showed a depth of 39 feet 6 inches at about 2,200 feet ahead of the present end of the south breakwater. So that, as this work was advanced about The Author. 1,120 feet, the 7-fathom line advanced about 1,620 feet. But the latest survey showed it only about 1,650 feet ahead of the breakwater end; so that it must have retired shoreward about 850 feet since 1906. The bottom was so flat, however, that the amount of shoaling or deepening due to this movement was not very great. At the present time, while depths of 38 feet 9 inches to 41 feet 9 inches at low water were found at a distance of about 1,600 feet seaward of the end of the works, depths of 36 feet 6 inches to 40 feet 6 inches at low water were also found close outside. These latter depths, however, were largely due to dredging, and only experience could show whether they could be maintained economically without some further extension of the works. Not only was the sea-bottom here very flat, but a spit, with 12 feet of water or less on it at low water of spring-tides, used repeatedly to grow out from the end of the Bluff as a base, between the northerly littoral current and the outflowing tide, and extended for a distance of about 600 feet seaward of the end of even the present south breakwater.[1] These works, therefore, were still about 600 feet behind the point to which he considered it might ultimately be necessary to extend them in order to place the end of the south breakwater beyond the influence of the end of the Bluff. This spit was of course now kept down by the dredging-operations, but the tendency to form was still there. He pointed this out when in office, and it deterred him from advising any sudden narrowing of the entrance, in view of possible further extension. With the present depths mail-steamers of 12,000 to 13,000 tons entered the port regularly, and recently a vessel of 18,000 tons entered and left in perfect safety. The 7-fathom line was, however, found to the south-east of the entrance at about half the distance at which it was found to the north-east, owing to the general trend of the coast-line, and this was obviously the reason that had suggested the plan shown by Major Harts. He felt certain, however, that, with local experience, Major Harts would appreciate the risks to vessels entering during stormy weather, which an entrance with this aspect would present.

It was scarcely correct to designate the Durban breakwater, as Mr. Berridge did, as of the rubble-mound type with solid capping. It was a compound type between the rubble mound and pell-mell block-mound. The rubble was only in the hearting, and was completely protected by concrete blocks. The work was, of course,

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[1] See Minutes of Proceedings Inst. C.E., vol. clxvi, p. 35, *Figs. 10*, *12* and *13*.

The Author. designed with a view to meet the local conditions, and with the exception of the washing away of the light blocks at the seaward end, against the use of which the Author had protested, the work had stood remarkably well. He was well acquainted with the grouted-block system, as he was a pupil and assistant of the late Mr. W. R. Kinipple, M. Inst. C.E., its inventor, and was afterwards his successor as Chief Engineer at Greenock; and he had made use of it in his design for the quay-walls at Durban. Mr. Berridge's word of caution as to the method of using the grout was quite in accordance with experience, and the Author thoroughly agreed with him in preferring neat cement grout, and as to the risk of using sand with it. Where it was worth while to grout up joints under water, it was worth while to make sure that it was successfully done.

With regard to Mr. Carey's remark as to there being only "two dependable observations" of current-velocities on the bar, the Paper stated that only two were obtainable *with a current-meter.* Very many were taken by means of submerged floats in all states of the tide and weather.

To have extended the breakwater to the east on a 1-mile radius until the two piers reached the 7-fathom line, as suggested by Mr. Cay, would have meant making both piers about double their present length at, of course, a very much larger cost. An eastern aspect certainly presented the advantage of working in the direction of the nearest deep water, and if the works had eventually to be extended farther this would have to be considered. The vast increase in the tonnage and draught of steamships since the Author took charge of the works had introduced considerations which might well vary preconceived opinions, and it seemed to him very difficult to say where this increase, if continued, would lead the harbour-engineers of the future.

Perhaps the best reply to Mr. Halligan's criticism would be that "nothing succeeds like success." The fact that Durban, with what he called a narrow entrance, although 600 feet wide, had been made one of the finest harbours in the world, and was regularly entered by steamships of 12,000 to 18,000 tons, fairly disposed of his objection on that score. His contentions, that the entrance should have been made 1,500 feet wide; that unless the ebb-tide had received some assistance from the upland water from the two poor little streamlets at the head of the bay, the entrance would have filled up long ago; and that neither the velocity of the ebb-tide, nor the present tidal volume of the bay need enter into the calculation in any way; would, the Author thought, rather astonish his confrères. Having previously dealt with Mr. Halligan's surprising theories

The Author. as to the width of entrances,[1] he need only say here that it seemed as if Mr. Halligan had confused the conditions affecting the wide deep entrances to great natural harbours on more or less rocky coasts, and those of small tidal lagoons or rivers debouching on sandy foreshores. With regard to the depth to which wave-action extended, Mr. Halligan was presumably aware that wave-disturbance sufficient to stir up fine sand had been found to extend to far greater depths than 60 feet, and, if he would read again the passage in the Paper (p. 6) referred to by him, he would find that the sand-bearing littoral current of ½ knot to 1 knot per hour was stated to be barely sufficient *of itself* to cause sand-travel; but that, aided by the oblique wave-action up the coast, it carried large quantities of sand *in suspension*. If Mr. Halligan's remarks as to oblique wave-action taking place "only during very violent alongshore gales" were correct as applying to New South Wales, they certainly did not apply to the south-east coast of South Africa, where the oblique action of the surf was constantly visible in the finest weather, and the influence of the waves on sand-movement, instead of being, as Mr. Halligan stated, very small, was, on the contrary, very great. There was also no doubt whatever that the main external conditions immediately affecting the entrance at Durban were not the great ocean-currents, but the in-flowing and out-flowing tides, littoral currents, waves, and surf-currents, and the consequent inshore sand-travel. He could not discuss Mr. Halligan's references to acceptance of "text-book statements," but he would say that he had never used the terms "seaman" and "layman" in any disrespectful sense. His conclusions were the result of careful experiment and long-sustained observation, on the part of himself and his assistants, as well as of former engineers; and he might remind Mr. Halligan that the main principles upon which the works at Durban had been successfully carried out had guided not only the Author, but also Sir Charles Hartley and Sir John Wolfe Barry when they were consulted.

Mr. Hammersley-Heenan had cited Port Shepstone as an instance where his study of the effect of tidal scour had led him to the conclusion that there was comparatively little scour in waters with depths exceeding 30 feet under circumstances such as prevailed there. Mr. Heenan was quite right so far as this so-called "port" was concerned, because it possessed a tidal compartment which probably did not hold more than about 1 to 1½ million tons of tidal water, and therefore with such a depth as 30 feet at the mouth of the river (if so

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[1] Minutes of Proceedings Inst. C.E., vol. clxxxiv, p. 248.

The Author. phenomenal a depth ever existed there) the surface velocity, except in spates or floods, would be exceedingly low, and the bottom velocity practically nothing. The Author knew this river well. The entrance was nearly closed by sandbanks under normal conditions, and the depth was only a few feet at low water, the works carried out hitherto having had practically no effect whatever. The depth of 30 feet never could have existed at the mouth of the river, unless when scoured out by some abnormal flood, in which case what became of Mr. Heenan's conclusion as to there being comparatively little scour at that depth? But the contention that tidal scour was of no value really required no further comment, except that the engineer must be guided by the circumstances in each case. In Durban the large tidal volume of the bay had been of immense service, and its combination as a scouring agent with dredging-operations had been the cause of the success attained. Without it, powerful dredgers, and plenty of them, would have succeeded, no doubt, as they had succeeded elsewhere, in cases where there was practically no tidal volume to rely upon; but it was perhaps unnecessary to add that the Port of Durban would hardly have relished the enormous additional cost. With regard to the founding of quay-walls directly on the sand in Durban Bay, and dispensing with a thin rubble foundation under them, this would appear to be a dangerous experiment, especially in such fine sand. In addition to the rubble underneath, there should be a toe of rubble to prevent any scour along the face from working underneath, which it would do the more easily if the blocks were founded directly on the sand. No such toe was mentioned by Mr. Heenan. As to the use of sand-pump dredgers and blasting at Congella for the removal of the stiff clay there, and reclamation of land, nothing could have been more uneconomical. The frontage of the land was only about 3 feet or so below high water of spring-tides, and it would have been actually cheaper to make a small half-tide dam well back from the proposed channel and enter into a contract to dig out the clay and wheel it on to the land. The clay was stiff and to some extent sandy, but not nearly so tenacious and difficult to dredge as the "boulder clay," or "red till," as it was called, large quantities of which the Author had removed with bucket dredgers from the navigable channel at Garvel Point on the Clyde. A much cheaper method of executing this work at Congella would have been to dredge out the channel with a powerful bucket dredger cutting her own flotation, and deposit the clay in the sea, instead of attempting to convey it on to the land. The sand-pump dredgers at work on the bar or in other parts of the

The Author.

Bay could then have deposited their loads of free sand in this channel, where one or two small stationary sand-pumps could have been employed in pumping it on shore. The average cost of dredging by the bucket hopper dredger "Otter" during a period of 5 years was given by Mr. Crofts as 5·44*d.* per ton, including repairs. A more powerful dredger with large buckets, well tapered in the body to facilitate their emptying themselves, would have dredged the Congella clay at a price certainly not in excess of this; and to pump the free sand ashore with stationary dredgers would not have cost more than, say, 1·5*d.* per ton—or at the outside, say, 7*d.* per ton in all. It would be interesting to know what this work had really cost. Latterly the special suction-dredger with cutting-gear, described by Captain Rainnie, was obtained, and, if the figure of 2·732*d.* per ton for such clay dredged and deposited on land was correct, this dredger must be doing exceedingly economical work. It was only fair to the engineer in charge at the time of the previous operations to say that, in the Author's opinion, he was unduly hurried by the authorities. There was no need for such haste, and the execution of the work by the crude methods adopted must have involved a serious waste of public money.

It was difficult to follow Mr. Leitch's contention that the superstructure of the breakwater carrying the rails for a block-setter, and that of the south pier, could have been dispensed with, as he did not suggest what might have been done in their place. With regard to his remarks about quay-walls, the original section designed by the Author was purposely made well on the safe side, as the system of construction was new, the workmen employed were inexperienced in the work, and the foundation was running sand with sometimes unexpected clay strata, while the filling at the back was also running sand pumped in by dredgers. As experience was gained of all these conditions the section was gradually modified, and there had been no failure. Cement was not so expensive as Mr. Leitch stated. The price was given on p. 26. Convict labour was largely used both at the breakwater and quay-walls, while large rubble stones or "displacers" were freely used in the manufacture of the blocks. He agreed with Mr. Leitch as to the value of mixing-machinery for concrete; but probably on the Rand now native labour was much more expensive than it was when he built the breakwater.

In reply to Dr. Owens, the bottom velocity of 0·7 mile per hour was measured by a current-meter, which was originally, the Author believed, designed by Messrs. D. and T. Stevenson, of Edinburgh, the constant used for the machine being determined by experiment.

The Author. The observation was made as close to the bottom as the rotation of the vanes allowed—say, 3 to 4 inches above it.

With regard to Captain Rainnie's remarks about the width of exposed harbour-entrances not being less than the length of the longest vessel navigating them, in view of the constantly increasing length, as well as beam, of steamships, this would be a somewhat difficult condition for the engineer to meet. But the Author was in full sympathy with him as to the responsibility attaching to the navigation of long vessels into a narrow entrance where outside cross currents and seas were apt to slue the vessel. He was of opinion that, although the 600-foot entrance had no doubt been productive of good in the matter of depth, it would have been found possible, with a moderate increase in the cost of dredging, to maintain adequate depths in the somewhat wider entrance shown on his plans, especially as the tidal volume between high and low water increased with the dredging-operations inside. He was bound to say, however, that, even with the present 600-foot entrance, frequent observation of large mail-steamers entering the harbour had led him to the conclusion that if the drawbacks alluded to by Captain Rainnie were really of a serious nature, the skill of the pilots at Durban overcame them very successfully. He quite agreed, however, with Captain Rainnie to the extent that even if some little additional width of entrance involved a certain loss of scouring-force, which the Author's somewhat wider entrance certainly would have done, engineers should avail themselves of the immensely powerful dredging-plant now procurable, within, of course, reasonable limits as to cost, if by so doing they would render the entrance materially safer for navigation, and make reasonable provision for the increasing length of steamships.

In reply to Mr. Ridgway, so far as the Author was aware, there was very little maintenance-dredging required in the harbour as against silting-up by the deposit of sand from outside. Even before the north and south piers were extended nearly so far, and when the entrance was much wider, the inside depths were very constant. In regard to the maximum velocities in the entrance-channel effecting scour, as alluded to by Mr. Smith, the banks in Durban Bay were at about half-tide level, so that the great inflow of the flood-tide took place immediately it had covered these banks, or during its third and fourth quarters; and the same principle applied to the ebb, namely, that the greatest velocity was attained before the banks were uncovered, or during its first and second quarters. Before and after these periods, on the flood and ebb respectively, the only water left to flow and ebb was that in the narrow channels which meandered through the banks. The Author

Mr. Smith must have been strangely misinformed as to the Dominion warship "New Zealand." That vessel entered the harbour immediately she arrived in the offing, in spite of the weather prevailing. She was not kept waiting ½ hour, and although the Durban bar certainly was one of the worst in the world when the Author first crossed it in 1888 to take charge, Mr. Smith's informant would have some difficulty in finding it now—as he would see if he looked at the depths on the diagram on p. 56.

Mr. Williams's comparison of the quantities dredged in successive years to obtain each extra foot in depth, so far from demonstrating that the extension of the north pier was not needed in order to make the most of all available scour, proved just the reverse; because he made it evident that every foot of increase in depth beyond what the tidal waters would maintain naturally required an increasing amount of dredging. Hence the Author's anxiety to utilize the natural forces to the utmost, so as to minimize the dredging. There could be no doubt whatever that if the north pier had not been extended, and the tidal ebb and flow had been allowed to waste its energy round the end of the short northern work, every foot in depth gained would have required a much larger proportion of dredging both to create and to maintain it.

He was in entire agreement with Mr. Berridge as to the pressure sometimes put by those temporarily holding membership or office in a governing body on their engineer, the only man having individual responsibility.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 4034.*)

"Opening Bridges over the Nile at Cairo."

BY ARTHUR JAMES KNOWLES, B.A., M. Inst. C.E.

(*Abridged.*)

IN continuation of the policy of opening up the west side of the Nile—the city of Cairo itself being on the east side—the Egyptian Government decided to make another way across the river by building two bridges about a mile lower down than the Kasr-el-Nil bridge (built in 1871). There is a large island here known as Ghezireh, the main channel being on the east side at the present time and only a small branch on the west side. At the time of Napoleon's occupation of Egypt—a little more than 100 years ago—the positions were reversed, the main stream being on the west side of the island. It being intended that the small channel should be available for the passage of boats, on account of the strong current in the main channel during the annual flood, it was decided that both bridges should be made to open. In order to follow the alignment of the road on the east side the centre-line of the main bridge is on the skew (25° 20′ 13″ off the square), but the small bridge is built square.

The main stream at the site of the bridge was about 212 metres (695 feet) wide, as compared with 400 metres (1,312 feet) at Kasr-el-Nil, and 535 metres (1,755 feet) at Roda bridge, 1 mile and 3 miles farther up respectively. The length of the present bridge was increased to 248 metres (813 feet 8 inches), on the square between abutments, corresponding to a length on the skew of 274·50 metres (900 feet 7 inches). The stream on the other side of the island is about 140 metres (459 feet) wide during flood, the small bridge being 125 metres (410 feet) long between the abutments.

The main stream, in consequence of the narrowness of the channel, is very deep, as shown in Fig. 1, Plate 3. The eastern half is 42 feet to 46 feet deep, and the western half runs down to

R.L. − 6·00 metres, giving 69 feet of water at low Nile, and 82 feet during the flood at the site of pier No. 5. Between this deep place and the west bank there was a mass of masonry, apparently built in pozzuolana, designed to protect the Ghezireh Palace (now a hotel), which was built by the Khedive Ismail on the bank of the river about 1869. The geological formation is sand and gravel, with occasional bands of black mud: there is no rock at any known depth.

The main bridge consists of four spans of 50 metres (164 feet) each between centres of bearings, and a Scherzer rolling-lift span of 72·10 metres (236 feet 6 inches) over all, giving an opening of 33·172 metres (108 feet 10 inches) between centres of piers. The lifting portion of the bridge is built square, though it rests on skew piers, and it is consequently difficult to know what to call the width of the opening. The distance between the nearest parts of the bridge when open for boat traffic is 88 feet, measured on the skew, but the distance between the piers on either side of the opening, measured square to these piers, is only 86 feet 6½ inches at the ordinary level of the water (R.L. 15·00 metres), and this is really the space available for river traffic. Even this space is slightly reduced, i.e., to 76 feet 4 inches, by two timber rafts, one on each side of the opening.

The girders are of the Warren type, with a single system of triangulation and vertical end-posts, the points of intersection of the diagonals with the bottom and top booms being 12·50 metres (41 feet) apart, this being consequently the distance between the cross girders. The angle of skew is such that the down-stream girder is displaced half a bay in advance of the up-stream girder, and by having a tie at the end-post of the down-stream girder, instead of a strut as in the up-stream girder, the intersections are brought opposite each other on the top and bottom booms, and the cross girders and overhead bracings are kept square with the centre line. The girders are 164 feet long and 26 feet 9 inches deep, the roadway being carried on the bottom booms and the top booms being connected by overhead bracing at each intersection of a diagonal.

The bridge is 19·608 metres (64 feet 3½ inches) wide between the parapets, the roadway being 39 feet 4½ inches wide between the curbs. The main girders are 43 feet 2½ inches apart, centre to centre, the footpaths being carried on outside brackets at each cross girder.

There are six piers and two abutments, all founded on caissons sunk under compressed air. The air-pressure in most cases corresponded with a head of 33 metres (108 feet 3 inches) of water at the finish, i.e., 47 lbs. per square inch. In several cases the water-level was above the normal and the final pressure above this, the maximum being 49 lbs. per square inch. The native workmen stood these high pressures remarkably well. There were only four deaths in any way attributable to work in compressed air, and though there were many cases of "bends," especially during the filling of the working-chamber with concrete, none of them were very serious.

The spans were all erected on a staging near the shore and floated out into position, except the lifting span, which was erected in place in the closed position by building out from either side.

The small bridge is 125·0 metres (410 feet) long between the abutments and 16·45 metres (53 feet 11½ inches) wide between parapets. It consists of two shore spans, each 101 feet 10 inches long, and a horizontal swing span of 206 feet 5 inches, giving two openings each 65 feet 7 inches wide for navigation. The roller-path is carried by a group of girders resting on four cylinders supported on two caissons. The girders of the shore spans are of the N type, with inclined ties and vertical struts, and the swing-span girders are of the same type.

A double line of electric trams, metre gauge, crosses both bridges, the rails being laid on the north or down-stream side of the roadway.

FOUNDATIONS OF MAIN BRIDGE.

The six piers and the two abutments are all founded upon caissons, as shown (Figs. 1, Plate 3), differing slightly in size and shape of the ends, but otherwise similar. Those for piers Nos. 1 and 6 are 20·71 metres (67 feet 11 inches) long and 5·0 metres (16 feet 5 inches) wide; those for piers Nos. 2, 3, 4 and 5 are 71 feet 7 inches long and 16 feet 5 inches wide; and those for the abutments are 65 feet 7 inches long and 15 feet 1 inch wide. The pier caissons have semicircular ends, and those for the abutments square ends with rounded corners. They are all parallel from top to bottom, the joints both vertical and horizontal being lapped, except the vertical joints of the plates in the sides of the working chamber, which are butted with inside and outside cover-plates. The working-chamber (Fig. 2, Plate 3) is 2·0 metres (6 feet 6½ inches) in height from the cutting edge to the roof; the side plates are 8 millimetres ($\frac{5}{16}$ inch) thick; and those of the roof 6 millimetres ($\frac{15}{64}$ inch). Above the roof plate are stiffening girders, 3 feet 5 inches apart, except near each end, where the spacing is increased to take the air-shaft. These girders are 16 feet 4 inches long and 1 foot 9½ inches deep, being carried on brackets attached to the side plates. The cutting edge is formed by the addition of a plate 8⅝ inches by ⅝ inch outside, and one inside 6¼ inches by ½ inch, and an inside angle-bar, which also supports the brackets. A brick lining was built all round the working-chamber, flush with the brackets for a height of 3 feet from the bottom, and then vertical to the roof, this part being 1 foot 9½ inches thick.

Above the roof-girders the skin-plating varies a great deal in thickness. The plates are all 3 feet 3⅜ inches deep and 11 feet 9¾ inches long, and are strengthened by two channel-bars riveted inside forming horizontal girders, and by six vertical girders on each side. The latter consist of a web-plate, 1 foot 7½ inches wide and $\frac{9}{32}$ inch thick, and two angle-bars at each side 2¾ inches by 2¾ inches by $\frac{9}{32}$ inch. There are four stays across the caisson between opposite pairs of vertical girders. Attached to the roof, 15 feet 1½ inch from each end, were the air-shafts, 1·0 metre (3 feet 3⅜ inches) in diameter, provided with a ladder and guides for the buckets.

From the top of the roof-girders for 13 feet 1½ inch, the plates are 4 millimetres ($\frac{5}{32}$ inch) thick. Then for 6 feet 6¾ inches in height the plates are 5 millimetres ($\frac{13}{64}$ inch) thick. In the next 6 feet 6¾ inches the plates are 6 millimetres (¼ inch) thick, then 6·5 millimetres ($\frac{17}{64}$ inch) thick for 9 feet 10 inches. Above this the plates are gradually reduced in thickness until the top of the vertical girders is reached, and the remaining height of 38 feet 11½ inches consists of eleven rings of plates 3 feet 3¾ inches wide and 3 millimetres (⅛ inch) thick, with one angle-bar in the middle of each ring. This exceedingly weak structure caused a great deal of trouble during the sinking.

On account of the great depth of water it was decided to lower the caissons on to the ground from a floating staging. This consisted of two specially built pontoons, 98 feet 5 inches long, 16 feet 5 inches wide, and 9 feet 6 inches deep, decked with 1$\frac{9}{16}$-inch planks and connected by bracing at both ends so as to leave a space between them 18 feet 5 inches wide and 79 feet 5 inches long. A well-braced timber staging was erected on these about 15 feet high above the deck, and on this rested six double girders, spanning the space between the pontoons. These were joined together by lattice bracings on the top flange and by six diaphragms and a bearing-plate near each end, where they rested on the timbers of the staging. On these girders were seated twelve screw-jacks, shown in detail in Fig. 3, Plate 3. Two other jacks were carried on timbers over the ends of the caisson, making fourteen in all, but these two did not take very much weight. The jacks themselves consisted of steel screws, 3 inches in diameter over the thread, which was $\frac{5}{16}$ inch deep and of $\frac{5}{8}$ inch pitch.

The space between the pontoons was first covered with timber planking on joists, and on this platform the working chamber of the caisson and the ring of plates above were erected and riveted. Large cast-steel hooks, shown in the Figure, were then placed under the cutting edge and joined by steel links to the screws of the jacks. The caisson was lifted clear of the flooring on which it had been built, by screwing up the jacks, and the brickwork lining was then built in round the sides of the working-chamber. When this was finished, the flooring between the pontoons was removed, and the caisson was lowered until the roof of the working-chamber was about level with the water. Concrete 1 metre thick was then deposited on the roof, and the rubble masonry filling was started on the top of this. The filling was composed of local limestone and 4–to–1 Portland-cement mortar, the cement being manufactured at Massara, about 14 miles up the Nile. The concrete consisted of the same mortar and broken silicified sandstone or quartzite from the Gebel Ahmar, near Cairo, in the proportion of 1 of mortar to 1½ broken stone. This masonry served two purposes at this period; it acted as kentledge to sink the caisson and as strutting to resist the pressure of the water. In lowering through the water, the permissible load on each jack was 25 tons, or 350 tons in all. Taking for example the position when the cutting edge was 32 feet 6 inches below the water-line:—

	Tons.
Steelwork of caisson weighed	83
Brickwork lining to working-chamber	81
Concrete and masonry above roof	797
	961
Displacement of water	800
Load on jacks	161

= 11·5 tons per jack.

Now 797 tons of masonry would give a height of about 11 feet 6 inches of solid filling over the whole area of the caisson, leaving 14 feet of caisson below the water-line unsupported by masonry. It was therefore built to be, at the stage under consideration, 6 feet 6¾ inches thick, including the concrete, over the roof, which would weigh about 450 tons, leaving 347 tons to be devoted to a lining wall and six cross walls at the vertical girders. The condition of things at the end of the sinking through the water of the caisson of pier No. 5 is indicated in Figs. 2, Plate 3. The water here was 69 feet deep, which was reduced to about 55 feet 9 inches by throwing in sand-bags and stone for the cutting edge to rest on. These were thrown in round the sides of the caisson, and also down the two air-shafts. The masonry, solid for 14 feet 9 inches above the roof, extended in the form of circumferential and cross walls for 36 feet farther, or 56 feet 9 inches above the cutting edge, giving a total load of about 420 tons on the jacks, or 30 tons on each.

As the caisson was lowered on to this artificial hill, it moved sideways and got over 2 feet out of position, and in spite of attempts to pull it back, it remained in that position, and was finally founded there. It was eventually decided to lengthen each leaf of the opening span by 8 inches, thus throwing all the piers west of the opening 1 foot 4 inches to the west of their original position, and enabling the upper part of the masonry of No. 5 pier to be built inside the temporary plates.

When the cutting edge was at R.L. −13 feet, the air-pressure was put on, reducing the load on the jacks by about 200 tons, and enabling the masonry walls to be carried up to the water-level. This was very necessary, as above the vertical stiffening girders—64 feet 6 inches above the cutting edge—the caisson consisted only of plates 3 feet 3¾ inches wide and 3 millimetres (⅛ inch) thick, with a circumferential angle-bar 2¾ inches by 2 inches by $\frac{9}{32}$ inch in the centre of each ring of plates. They were held together by ⅜-inch rivets hammered up cold, a strip of tarred brown paper being inserted in the lapped joints to keep them water-tight. Well-braced timber frames were inserted across the caisson to support these thin sides, but it was very difficult to prevent them buckling and getting out of shape.

The type of air-lock used is also shown in Fig. 2. It consisted of a steel cylinder 6 feet 6¾ inches in diameter and 8 feet 10 inches high, bolted to the top of the air-shaft, which was 3 feet 3⅜ inches in diameter, and provided with a door in the side and another door opening downwards into the air-shaft. This latter was pulled up by a chain when it was desired to shut it. The compressed air entered through an adjustable back-pressure valve of a type in which the compression of the spiral spring is increased as the pressure becomes higher, thus ensuring the shutting of the valve on a sudden lowering of the pressure in the caisson. A vertical pipe just inside the lock supplied compressed air to a small reciprocating engine working a hoist for lifting the skips up from the working-chamber. The contents of the skips were emptied into the tube shown on the left, the lower door being, of course, shut and the upper one open. When the tube was full the upper door was closed, the air was let out and the lower door opened to discharge the material. A similar arrangement—inverted—was used for putting in the concrete for filling the working-chamber, and is shown on the right of the lock. The concrete dropped down the air-shaft and was then shovelled into place by men in the working-chamber. Besides the buckets and muck-shoots on the locks, two ejector-pipes were fitted in the roof of the working-chamber, and extended up through the masonry to above the top of the caisson, where they were bent at right angles so as to throw the sand clear of the pontoons. These pipes were 80 millimetres ($3\frac{5}{32}$ inches) in diameter, made of wrought steel, and were provided with a cock against the roof, and a flexible hose from this to the floor. The material was generally passed through a coarse sieve to remove the pebbles before being blown out. These ejectors worked very well, but, of course, they used a great deal of air.

The air-compressors were mounted on boats, and could thus be easily moved about from pier to pier. They were of the horizontal tandem type, running at 28 revolutions per minute, and gave 4·22 cubic metres (148 cubic feet) of free air per minute. In the earlier stages of sinking only the buckets were used for disposing of material, as it was too muddy for the ejectors, and there were at the most twenty men below at one time. This gave 450 cubic feet of air per man per hour. In the later stages, when the ejectors were being used, two compressors were employed and fewer men—only ten as a rule—and the air was probably purer, being more frequently changed. The pipes between the compressors and the locks—flexible rubber pipes 113 millimetres ($4\frac{7}{16}$ inches) in diameter, internally wired—and the locks themselves were covered with canvas or matting and kept wet, to cool the ingoing air, but it was frequently as hot as 95° F., and being saturated with moisture, was very trying for the men.

The number of men who actually worked in compressed air during the sinking of the piers and abutments of the bridges was 493. Of this number about one-fifth were reported as suffering from illness more or less serious; one man being attacked three times, thirteen men twice (one fatally), and eighty-six once (three fatally), making 115 cases of illness dealt with by the doctor.

Of these 115 cases four were fatal; one resulted in permanent deafness, and the remaining 110 completely recovered.

The four fatal cases occurred under the following circumstances:—

(1) The man felt ill while in the caisson and came up the ladder unaided. He died suddenly three hours after coming out of the lock. The post-mortem examination showed evidences of mustard plasters on his back, and inquiries elicited the fact that he had been suffering from heart-troubles for several days, but had kept the fact quiet so that he might go on working. Air-pressure 16 lbs. per square inch (1·1 kilogram per square centimetre).

(2) The man died suddenly after leaving the works, 1½ to 2 hours after coming out of the lock. Air-pressure 33 lbs. per square inch (2·3 kilograms per square centimetre).

(3) The man died suddenly after leaving the works, 1½ to 2 hours after coming out of the lock. Air-pressure 39 lbs. per square inch (2·7 kilograms per square centimetre).

(4) The man was in hospital for 15 days before he died suffering from retention of urine, due to slight paralysis of the lower part of the body. Death was due to hæmorrhage of the spinal marrow. Air-pressure 43 lbs. per square inch (3·0 kilograms per square centimetre).

The hours of work and the time allowed for de-compression were as follows:—

HOURS OF WORK.

Pressure.	Duration of Work.
Up to 28½ lbs. per square inch	Two 8-hour shifts.
28½ to 40 " "	Three 8- "
40 to 45½ " "	Three 6- "
45½ to 50 " "	Six 4- "

During the final stages of concreting the working-chamber, 3-hour shifts were worked during the day only; that is to say, that an individual man only did 3 hours' work in compressed air in the 24.

RATE OF DE-COMPRESSION.

Pressure.	Time for De-compression.
Up to 35½ lbs. per square inch . . .	1 minute for each 1·4 lb. (0·1 kilogram per square centimetre).
35½ to 42½ " " . . .	35 minutes.
42½ to 45½ " " . . .	40 "
45½ to 50 " " . . .	45 "

The working-chamber was lighted by electricity, and the air-locks in summer were covered with matting, which was kept wet.

The labourers were all natives of Egypt, supervised by European (French, English and Italian) foremen and inspectors. They had all to be passed by the doctor in attendance before being allowed to enter the compressed air.

No medical air-lock was provided by the contractors, but the inhalation of oxygen was used a good deal in cases where the heart was affected, and is reported to have given satisfactory results.

The maximum pressures attained during the sinking of the piers and abutments was reached in the case of pier No. 2, where a pressure of 49 lbs. per square inch was required. This is simply the equivalent of the head of water, and was quite possibly exceeded in reality, on account of bands of clay in the ground and the filling of the working-chamber with concrete retarding the escape of air.

The caisson for No. 6 pier had to be lowered through the water on to a very steep slope, there being a difference of level in the ground of 32 feet 9¾ inches in the length of the caisson and 16 feet 5 inches in the width, or slopes of 2 to 1 and 1 to 1 respectively. Here one advantage of the floating staging was evident, as the caisson could be moved about, hanging between the pontoons and used like a diving-bell to level off a platform for itself to rest on, being raised or lowered by the screw-jacks as necessary.

The levels to which the caissons were sunk are shown in Fig. 1, Plate 3, and the normal low-water level was 49 feet above sea-level. The top of the permanent caisson is at a level of 44 feet, above which there were temporary plates 11 feet 6 inches deep, bolted to a circumferential angle-bar, enabling the neat masonry to be built within until the level of the river reached 56 feet. This neat masonry was faced with granite from Assuan.

The rate of sinking under compressed air from start to finish, from the time the caisson touched the water to the time it reached its final position, was as follows:—

	Total Depth sunk.			Number of Days.	Rate per Day.		
	Metres.	Ft.	Ins.		Metre.	Ft.	Ins.
Boulac abutment . . .	28·85	94	8	109	0·266	0	10¼
Pier No. 1	33·20	108	11	90	0·368	1	2
„ 2	33·00	108	3	96	0·344	1	1
„ 3	33·05	108	5	85	0·390	1	3
„ 4	33·10	108	7	103	0·319	1	0½
„ 5	35·20	115	6	134	0·263	0	10¼
„ 6	34·25	112	4½	145	0·236	0	9
Ghezireh abutment . .	29·20	95	9½	170	0·172	0	6¾

The most rapid sinking was 0·42 metre (1 foot 4½ inches) per day at No. 4 pier.

SUPERSTRUCTURE OF FIXED SPANS.

There are two fixed spans on each side of the Scherzer rolling-lift span and its supporting tracks, which are placed in the middle of the river. The girders are of the Warren type with a single system of triangulation and vertical end-posts, the bays being 12·50 metres (41 feet) long. A cross section of the bridge is shown in Fig. 4, Plate 3, showing a cross girder 5 feet 3 inches deep in the middle, the footpath brackets outside the main girders and the overhead bracing between the top booms. The cross girders being 41 feet apart, the longitudinals between them are of that length and 3 feet 7 inches deep, those under the tram-rails being 4 feet 1 inch deep. The floor is composed of buckled plates covered with cement concrete and 2 inches of asphalt, the footpaths having flat plates covered with cement concrete and 1 inch of asphalt. A double line of tram-rails, metre gauge, is placed on the down-stream side of the road.

On account of the great depth of water, the contractors decided to build the main spans near the shore and float them into position. A staging was accordingly constructed on timber piles alongside the shore on the Ghezireh side of the river, the piles being spaced so that two gaps could be made in the staging into which pontoons could be floated to carry the spans. A travelling crane, worked by hand, capable of lifting 10 tons, ran along the staging, for use in erecting the girders.

The pontoons were built of steel, 98 feet 5 inches long, 24 feet 7 inches wide and 11 feet 6 inches deep. The plating was 6 millimetres (¼ inch) thick. A strip of tarred cotton cloth was put between the lap joints of the plates and made them quite watertight. The deck-joists connecting the ribs were quite small and there was no decking on them.

When the riveting of a span was finished the girders were supported at the ends only by taking away the intermediate blockings. The staging was then cut and the pontoons, weighted with sand-bags to draw about 6 feet of water, were introduced below the girders and packed securely with large wooden wedges below the bottom booms. These wedges rested on a strong timber staging about 18 feet high, built upon the pontoons. A couple of timbers connected the two pontoons, and round steel bars with adjusting screws connected the pontoons to the girders and prevented any rocking of the former.

The sand-bags were now removed, allowing the pontoons to take the weight of the span and enabling the supporting blocks at the ends to be removed, thus getting it afloat. Concrete blocks to act as anchors had previously been dropped into the river with wire ropes attached to them, and these were hauled on with winches on the pontoons to get the span into its place. As soon as it was over its bearings, the sand-bags were put back, and the span was lowered down on to timber packings on the bearings, after which the pontoons could be taken away.

SCHERZER ROLLING-LIFT SPAN.

The opening span has two leaves, as shown in Figs. 1 and 5, Plate 3, each 19·406 metres (63 feet 8 inches) long, and is constructed on the square, the leaves rolling back parallel to the central line, although the piers carrying it are on the skew. Consequently the break in the roadway, which marks the end of the opening part, is at the outer end of the girder carrying the track on one side, and 22 feet 8 inches behind the end on the other side. In other words, the outer end of the track (on which the opening part rolls back) is over the pier on the one side and nearly 23 feet behind the pier on the other side.

Advantage is taken of this fact in the design of the two leaves. Under the dead load both leaves are in equilibrium, resting on the track, the overhanging portion being exactly balanced by the counterweight in the box at the rear. Under the live load, however, one leaf is supported 22 feet 8 inches in front of the end of the track, the remaining 41 feet of its length acting as a cantilever. The other leaf on the same side of the bridge is supported by the outer end of this cantilever at one end and by the track girder at the other end, the positions being reversed on the other side of the bridge. The support at the meeting of the outer ends of the leaves is shown in Fig. 6, Plate 3, the single centre casting resting on the lower of the two others on one side of the bridge and the upper one resting on the single centre casting on the other side.[1]

The cost of the main bridge was £329,000 and of the small bridge £78,000, and the time occupied in the construction 4 years.

The bridges were designed in the Public Works Department of the Egyptian Government and were constructed and erected by the Compagnie de Fives-Lille of France, who were represented in

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[1] A detailed description of the Scherzer rolling-lift principle as applied to opening bridges is given in "Walney Bridge, Barrow-in-Furness," by G. C. Trewby. Minutes of Proceedings Inst. C.E., vol. clxxxii, p. 265.

Egypt by Mr. E. Richard. The Author acted as Resident Engineer for the Egyptian Government under Mr. A. H. Perry, Under Secretary of State for Public Works, and Mr. M. Macdonald, C.M.G., M. Inst. C.E., who succeeded him when the works were approaching completion. The thanks of the Author are due to Mr. H. E. Kent, his Assistant on the works, and to Mr. E. Richard, for their valuable assistance in the preparation of this Paper.

The Paper is accompanied by nineteen drawings, from which those forming Plate 3 have been selected.

(*Paper No. 4058.*)

"Renewal of Large-Span Girders in Southern India."

By Percy Rothera, M. Inst. C.E.

The South Indian Railway Company has carried out during recent years a systematic renewal of all the girders on the main line of its metre-gauge system, rendered necessary by rapidly developing traffic, and the consequent use of heavier types of engines. Up to 1911 no serious difficulties were encountered in the work, which had been confined to the renewal of plate-girder spans of 70 feet and under; but on the northern sections of the main line there are a large number of bridges with lattice girders of spans of 100, 120 and 150 feet which had to be renewed, and the problem of the best method of renewal of these had to be faced.

The following is a description of the method adopted in renewing the eighteen spans of 120-foot girders over the Palar River.

The old girders which were erected when the line was first constructed between 1876 and 1878 were of the Whipple–Murphy type with pin-connected joints, built by the Patent Shaft and Axletree Company, and were of a very light construction. These it was decided to replace by new girders having riveted connections and of much more rigid construction, being designed to conform with the 1908 Standard Bridge Rules of the Government of India.

Site.—The Palar River, in common with many of the rivers in Southern India, is for the greater part of the year usually a dry arid stretch of sand, but is liable to sudden floods, and then becomes a raging torrent in which only a structure built on very good foundations can stand. The problem therefore was to evolve a method the adoption of which would entail the least risk of damage to the new spans while being erected and inserted, and also one that would cause the least interruption to traffic in the event of a flood. The bed of the river is fairly regular throughout its width, and slopes gradually from the north abutment to the south. Bed-stone level at the north end of the bridge is 21 feet above the river-bed, while at the south end it is 25 feet.

The usual practice in Southern India is to take advantage of the natural conditions afforded by dry rivers; and in works of this nature the traffic is carried on over a temporary diversion whilst the work is in progress; but in this instance it was realized that it would be impossible, except at great expense, to make a diversion capable of withstanding floods, and therefore in erecting the girders some method had to be adopted under which traffic could be quickly turned over the permanent bridge should the necessity arise.

Scheme for Renewal of Girders.—In order to attain these two objects, it was obvious that some method by which the new spans could be erected away from the bed of the river and inserted upon the piers complete was better than erecting them in situ, but the problem then arose of getting them into position, and incidentally of removing the existing spans.

To overcome this difficulty, the Author conceived the idea of taking the new spans up sloping ramps erected temporarily in line with the piers, the spans being carried on special trollies designed to fit the gradient of the ramps and simultaneously lowering the old spans in a similar way on the other side of the piers by coupling the old spans to the new by wire cables running over the piers, thus utilizing the weight of the old spans in assisting the new girders up. For the balance of power required, the ramps on which the new girders were raised were fitted with a double Abt rack-rail as used on the Nilgiri mountain railway (a part of the South Indian system), into which pinion-wheels mounted on the ramp-trollies engaged. These pinion-wheels were connected by gearing with worm-wheels, thus not only reducing the power required but at the same time providing an efficient lock on the movement of the trollies in any position.

To convey the new spans which had been erected in the building yard to the lower end of the ramps, they were carried on two trollies, called, for the sake of convenience, the horizontal trollies, running on low tracks in the river-bed laid parallel to the centre-line of the railway. These trollies were so designed that they were the same height as the deeper end of the ramp-trollies when the latter were at the bottom of the ramps. In the building yard the service tracks were run into a cutting so that the tops of the trollies were level with the girders as built, launching ways being provided at necessary intervals in the sides of the cutting to admit of the spans being moved on to the trollies. To facilitate the handling of the spans during the process of insertion and to avoid having to jack them up and down, they were moved horizontally on steel rollers, and to prevent the rollers from getting out of place they were to run between two channel sections, one of which overlapped the other. The lower channels were fitted permanently to the horizontal and ramp trollies and the upper channel was fitted temporarily to the bottom of the girders.

The process under which the work of removal was carried out was therefore to load a span on to the horizontal trollies in the building yard and to bring it out into the bed of the river to the foot of the ramps, where it was transferred on to the ascending ramp-trollies. After this had been done, the old span was pulled out from the piers on to the descending ramp-trollies, which had previously been coupled by wire cables to the new span trollies. When the new and old spans were loaded on their respective trollies, the new one was worked up the ramps by means of the gearing in the trollies, the old one meanwhile descending on the opposite side. On arrival at the top of the ramps, the new span was pulled from the trollies on to the piers; it was then jacked up, the rollers removed, and finally it was bedded in its permanent position. Under this method of erection, it was estimated that a span would be exposed in the bed of the river for not more than 24 hours, while the bridge itself would actually be out of use for a considerably less time, should the necessity for using it arise owing to the river being in flood. It was also estimated that one span could be inserted per week, thus ensuring, with some degree of certainty, the completion of the work during one season.

Erection of Girders.—This method of renewal having been approved of and adopted, the work of putting together the new spans, built by the Horsely Company, was commenced in the building yard on the 1st November, 1911.

The building yard was located on the north-east bank of the river, where the ground is about 6 feet above the level of the river-bed (Fig. 1, Plate 4), and which site is to some extent protected from flooding by the natural formation of the river. As a protection from flood a bank was thrown up along the river edge of the ground, and the work of putting the girders together was able to go on uninterruptedly throughout the monsoon months.

The work of erection was mainly carried out by Moplah (West Coast) coolies specially imported, they being more capable than the labour locally available. Tamil blacksmiths and carpenters were, however, to a certain extent, employed in minor works. The girders were received from England in batches of three spans, and on arrival were at once put together, as this was found to be the quickest way of sorting the materials. They were erected in four rows, one behind the other, to facilitate subsequent handling (Fig. 1). Separate gangs of twenty men under a maistry were employed on each girder and would assemble it sufficiently to commence riveting in 7 days.

In each span about 6,600 $\frac{7}{8}$-inch and 1-inch field rivets had to be put in. The question of using a pneumatic riveting-plant was considered, but it was found that this would not be economical, consequently all riveting was done by hand. A riveting gang, consisting of one riveter, one holder-up, two hammermen, one hotter and one bellows boy, put in on an average 100 rivets per day; the largest day's record being 135 rivets.

As soon as the girders were riveted together, they were handed over to the painting contractor, and, after being thoroughly scraped, were painted with two coats of graphite paint manufactured by the Shalimar Paint Company, of Calcutta. While the painting was going on, carpenters were engaged in fixing the teakwood cross-sleepers, which, as is usual in Indian practice, rest directly on, and are fixed to the rail-bearers, there being no flooring or ballast.

The erection work went on steadily throughout the wet months, and by the time it was possible to commence insertion of the spans, sixteen out of the eighteen were complete, with the exception of the end rail-bearers and their sleepers. These, owing to the method of insertion, could not be fixed until the girders were in position on the piers, as they project beyond the ends of the main girders so as to ensure a uniform spacing of cross-sleepers over the piers. They were, however, taken up with the girders and were easily inserted from the piers.

Description of Temporary Arrangements.—While the work of fitting up the girders was in progress, work was also going on in connection with the temporary arrangements required to insert them. As jacking was to be avoided as far as possible, the girders were moved horizontally on steel rollers. The levels were therefore so arranged throughout the process of insertion that this could be done, the girders being first rolled on to the horizontal trollies, then from these to the ramp-trollies, and finally from the ramp-trollies on to the piers (Figs. 2 and 3, Plate 4).

In order to provide a roller-path clear of the permanent bearings of the girders, and also to make each ramp when erected against the piers serve for the erection of two spans, temporary extensions (Fig. 4) were fixed to the ends of the main girders so that the roller-path was actually on the centre axis of the piers. To fix these extensions a length of 2 feet of the cover-plate of the end members of the girders was removed, and on the inside of the channels composing the bottom member pieces of the same section channel were riveted, these pieces projecting 14 inches beyond the end of the girder. These additional channels were drilled to correspond with the rivet-holes in the permanent girder, and extended only so far into the end connection as was sufficient to carry the weight, thus allowing as many as possible of the permanent rivets to remain untouched. These extensions were connected top and bottom by ¾-inch plates, the upper one being carried for a short distance up the end member to act as a saddle and give additional support, while the lower plate carried a 3-foot length of 10-inch channel which formed the top plate of the roller-path. The lower path for the rollers was a 12-inch channel on the trollies, while 12-inch H irons on timber packings were used in the building yard and on the piers. The rollers were 3½-inch steel pins 8 inches long, and were originally carried in bearings fixed to the upper channels, but this arrangement proved unsatisfactory owing to the difficulty in ensuring that the bearings were square to the path, while the friction of the rollers in their bearings made it very hard to move the girders. The bearings were then removed and the upper channel allowed to rest directly on the rollers; and to ensure the rollers keeping to their correct distance, they were mounted in cages of threes which were fed in under the upper channel as required.

This arrangement worked exceedingly well and was used throughout the whole work. With treble tackles from each end of a girder to winches, eight men were able easily to move a span, and while the overlapping of the roller channels kept the span in the proper direction, it provided ample play for manœuvring the span when such became necessary.

Each of the horizontal trollies referred to above, which were used to convey the girders from the building yard to the foot of the ramps, was made from a pair of old engine-frames, and the frames were spaced 15 feet apart between centres, so that when loaded the centre of each new girder rested over the centre of a frame (Fig. 2, Plate 4). Across the floors of these were fixed two joists, over which rested cross girders carrying on them a third joist, on the top of which was riveted the channel forming the roller path, the top joist being long enough to clear the engine-frames so as to admit of its being connected to the channels used for launching the girders in the building yard and to the ramp-trollies in the river-bed. The engine-frames were braced to each other laterally so as to make them as rigid as possible. When these trollies were loaded with a span, the front and rear trollies were coupled together by wire cables fitted with union screws which conveyed the pull from one to the other. The trollies with their load were pulled out from the yard to the foot of the ramps by two treble tackles fixed to the draw-bars of the leading frames, the other end being anchored to the tracks on which the trollies ran. The motive power was manual, sixty coolies being found necessary to pull each span out, 12 hours being taken for the span farthest from the building yard, a distance of half a mile.

The ramp-trollies (Fig. 2), which were specially designed for the work by the Author, were built by Messrs. Burn and Company, of Calcutta. They consisted of plate side-frames, the lower edges of which were parallel to the ramps while the upper edges were horizontal. These side-frames on their lower edge carried cast-iron bearings for the axles, and on the top were connected by cross girders supporting a similar joist to that used on the horizontal trollies, on which was fixed the channel forming the roller-path. In order to utilize metre-gauge wheels the trollies were designed to the same gauge, and originally each trolly was fitted with five pairs of wheels, but it was afterwards found that the trollies were so rigid in themselves that the centre wheels were useless, and they were removed, so as to facilitate the handling of the trollies when moving them from ramp to ramp. The wheels of the trollies used for the new girders were fitted with broad-gauge axles having journals 4¼ inches in diameter, the two inner axles carrying spur wheels which worked in the rack fixed on the ramps.

The gearing on the trollies was for safety made in duplicate, but as it was impossible to ensure that both sets of gears would always divide the work equally, each set was designed to carry the whole load. To the spur-wheels cast-iron pinion-wheels were rigidly bolted, and these were connected by idler-wheels to a shaft carrying a small pinion-wheel, and also, on the outer end of it, a large worm-wheel, on which worked a worm lying parallel with the axis of the trolly, in which position it was clear of the girder when the trolly was loaded. The worm-shafts were fitted with handles, and in order to ensure the gears being worked exactly together the centre handle was common to both shafts, while, owing to the greater depth of the tail end of the trolly, an additional idler in the back gearing reversed the motion of the worm.

This was arranged with the idea of ultimately fitting electric motors to these trollies, in which case this arrangement would cancel all thrust in the bearings. Motors were not, however, fitted for the erection of the Palar bridge spans.

For the calculation for the gearing required the following figures were adopted. The weight of the new spans as inserted was approximately 100 tons, i.e., 50 tons on each trolly, while the weight of the old girders was calculated at 60 tons, or 30 tons on each trolly. For friction, a coefficient of 0·1 was taken for both trollies, which included the friction of the wheels on the rails and of the journals in their cast-iron bearings.

These figures gave, in the case of the old spans, a force acting down the 1 in 6 ramp of 1·86 ton, while for the new spans they gave a force of 12·9 tons, leaving a net balance of 11·04 tons to be overcome in raising the new girders. To this must be added friction in the gears themselves and their bearings, and for these a coefficient of 0·2 was taken on the force required to move the girders, i.e., 11·04 tons, bringing this up to a total pull of 13·24, or, say, 14 tons.

The accommodation on the trollies was only sufficient for eight or at most ten men, and, assuming each man to be capable of exerting a force of about 18 lbs. on a winch-handle, meant that the load on the gearing had to be reduced to somewhere about 180 lbs.

The size of the lowest pinion-wheel was governed by the size of the spur-wheels, which were of the Nilgiri Railway standard pattern and could not be altered, so that to get the maximum reduction the upper pinion-wheel was made as small as possible while the worm-wheel was made as large as could be conveniently fitted to the trolly. When worked out this arrangement was found to be correct, and the final load on the crank-handles was calculated to be 182 lbs., while it was estimated that the speed up the ramps would be about 1 foot per minute. That these figures were very nearly correct was proved by the fact that on occasion ten coolies did actually take the loaded trolly up the ramps, though it was certainly hard work for them, while the average speed throughout the journey up was a little less than 1 foot per minute. Before the first girder was inserted the trollies were tested with a dead load of 30 tons of rails, it being impossible to get a larger load on to them. It was at once found that the pinion-wheel shafts were too long between their bearings, and additional bearings were fixed as close as possible on each side of the pinion-wheels on each shaft. When these had been fitted the trollies were again tested, and worked quite successfully in this respect.

Considerable trouble was, however, experienced with one of the trollies in the early stages of the work, owing to the teeth of the gear-wheels breaking in a way which at first was difficult to account for, as they broke not only when the trolly was loaded, but also when it was coming down the ramps under no load at all. The cause was finally traced to the fact that the rack spur-wheels on the trolly were a tight fit on the axles, whereas it was necessary that they should be free to revolve on these axles, owing to the fact that the spur-wheel is 2 inches less in diameter than the adhesion-wheels. When this was discovered, the wheels were taken down and freed, with the result that the trouble was cured. With this exception the trollies worked perfectly, and the second trolly went through the whole of the work without a single mishap.

The trollies used for the old spans were of the same design, with the exception that they were not fitted with gearing, while the wheels and axles were of the ordinary metre-gauge type, with journals 3¼ inches in diameter. No trouble of any sort was experienced with these trollies.

The steel-wire cables used for coupling the trollies were 1 inch in diameter, having a breaking strain of 30 tons. The calculated load on these cables was only 6 tons, but as the effect of one parting would have been disastrous they were used in duplicate, each cable having its own separate connections to the trollies. One end was fixed to the trollies by shackles, while the other end was taken to a screw union to allow for adjustment. They were carried across the piers in a chase cut in the masonry, so that they lay below girder bed-level, and were thus clear of the packings under the joists. Rollers were fixed at the ends of the piers to carry them.

The ramps (Figs. 2 and 3, Plate 4), which were designed so as to facilitate erection and removal, were constructed of Krabark or Poona wood, which is grown in Siam, and has only recently been introduced into India. It proved very suitable for the purpose, being a wood having a long-grained fibre, but at the same time being easy to work. It in many ways resembles pitch pine, and though liable to crack in the sun it does not appear to warp much. The bents were constructed of 10-inch by 5-inch section timbers, and were erected in pairs 4 feet apart between centres, braced together by 5-inch by 2-inch bracings, each pair forming a trestle. The trestles were spaced 16 feet from centre to centre and between them were diagonal struts of 10-inch by 5-inch section, carrying a cross timber under the stringers. The bents and diagonals were still further braced together by old rails running throughout the length of the ramp. The stringers were 10-inch by 10-inch timbers, spaced 3 feet 6 inches apart between centres and fixed to the bents by tie-plates and bolts. On these rested the cross sleepers which carried the rails and the rack-bars. In order to allow for adjustment in the alignment of the track, to meet any possible differences in the lengths of the girders, the sleepers were not fixed to the stringers, but to take the downward thrust from the rack-bars angle-chubs were fixed at intervals to the stringers, against which the sleepers rested. The rack-bars, which are bolted to their chairs, which in turn are fixed to the sleepers, ensured the correct spacing of the latter. The trestles were bedded on a platform of old sleepers resting on a sandbank, the depth of which varied with the inequalities of the river-bed, as it was essential that the top of the trestles should be as nearly as possible at the same level throughout the work to allow the ramp and horizontal trollies to meet correctly. It was realized to begin with that there might be some difficulty in this, and the original intention was to allow for a gap between the two trollies, the length of which would possibly vary, the intention being to close this gap with a length of channel section cut to suit. It was found, however, that although the differences were slight, this method entailed the use of several different lengths of closure channels, the length of which could only be found after the spans had arrived on the spot, causing delay. Finally a gauge was made to the correct length at which the ramp-rails and horizontal track-rails should be at the same level, and any necessary adjustments were made in the horizontal track rail-level after the ramps were completed, but before the girders arrived. This method was a great improvement on the previous one, and after its adoption no trouble was experienced in getting the two trollies to meet correctly. This difficulty was not experienced at the top of the ramps, as on the pier the channels rested on wooden packings, which were only adjusted after the girders arrived at the top of the ramps. No closure channels were used here, but the pier channel was carried out so as to rest on the ramp-trolly itself to ensure an absolutely correct fit and effectively bridge the gap between the trolly and the masonry of the piers.

To cancel any possible thrust which might come down the ramp, the ends were originally made up with sand for a length of 15 feet, but it was found to be difficult to pack the road on this part in such a way that there should be no settlement when the load came on to it, considerable trouble being caused on one or two occasions when the trollies reached the end of the stringers, owing to the bank having settled. Latterly stringers resting on short trestles were carried down through this sand end, after which there was no more trouble. With the exception of the ends, the ramps showed no signs of settlement throughout the work, nor was any other trouble experienced from them. The ramps used for the old spans were built to exactly the same design, with the exception that they were not provided with rack-bars. In all there were three ramps on each side of the bridge, the idea being that, while one pair was in use, the other one could be dismantled and re-erected; and when the work was in full swing this was found to be just possible, the third trestle usually being ready when it was required for the next span. No machinery was employed in dismantling, removing, and rebuilding the ramps, all the work being done by hand, and two gangs of about forty coolies each were continuously engaged in the work.

Insertion of Girders.—As soon as the water in the river had subsided sufficiently to allow of work on the temporary diversion of the railway being completed this was put in hand. The diversion was 1 mile long, and it was kept as low as possible in the river, only two openings of 30 feet each being provided, one in the bed of the river itself and one on the south side, both crossing irrigation channels. They were carried on temporary sleeper-stacks on boulder flooring in the usual way. The diversion was finally completed and traffic turned on to it on the 8th March, 1912. There was much work to be done on the old bridge before the girders could be inserted, as, owing to a difference in depth between the roller and the fixed ends of the old girders—both ends being alike in the new spans—the bed-stones on every alternate pier had to be lowered 6½ inches. New bed-stones also had to be put in on all the piers to carry the rail-bearers, which in the old girders rested on timber packings. Owing to the confined space available for work these bed-stones were constructed of cement concrete, which thus formed monolithic blocks the width of the piers and became incorporated with the original brickwork, the sides of which were left rough on purpose. As soon as this work had advanced sufficiently to allow the concrete a sufficient time to set, the first span was loaded on to the horizontal trollies on the 28th March. It was not, however, brought out into the river until the 11th April, owing to a delay in getting some of the final fittings for the ramp-trollies, on which date it was loaded on to the ramp-trollies. Some considerable time was lost over this first span, owing to having to drill the men, and the old span was not pulled out on to its trollies until the morning of the 13th. As soon as this was completed, the trollies were started up the ramps, and the span was successfully pulled in over the bed-stones by the evening of the 13th April.

Owing to the breaking of teeth in the pinion of one of the trollies the second span was not brought out and loaded on to the ramp-trollies until the 22nd April, and its insertion was completed on the following day. The first two spans were inserted at the northern end of the bridge, where the river is driest, but arrangements were now made to move over to the south end and work backwards so as to ensure being out of the deep part of the river before the floods came down. This change delayed matters somewhat, and the third span was only started on its long journey across the river on the 3rd May and was inserted on the 4th. Matters now began to run more smoothly, and, as the men began to understand the work, better progress was made. On the 23rd June the eleventh span was inserted, the time taken from the arrival of the girder at the foot of the ramps until it was in position over the piers being only 4½ hours.

Unfortunately on the 24th June cholera broke out in the Moplah camp, with the result that all the labourers disappeared, and for a week the works were practically deserted. The cholera having been stamped out, the local labour was gradually coaxed back, and the twelfth span was inserted on the 4th July with practically local labour only. After this the Moplah labour began to return and the work went forward again somewhat more briskly, but the effects of the cholera were noticeable in the progress of the work for some time afterwards. As the lead on the spans got shorter the work naturally proceeded quicker, and on the 20th July the fifteenth span was started from the dock in the early morning and was up in position on the piers before dark, the actual time being just 12 hours.

Matters now went on smoothly and on the 8th August the eighteenth and last span was inserted, 16½ weeks from the date on which the first one went in. The laying of the permanent way had been proceeding steadily, and as soon as the last rail-bearers had been inserted and riveted up, it was linked through and the bridge was opened for traffic on the 20th August, 1912, the traffic having been off the bridge for 5½ months.

Before the bridge was opened it was tested under a load of 120 tons. The deflection under a standing test was found to be 0·40 inch, or $\frac{1}{3600}$ of the span, while the permanent set was only 0·06 inch. Under a running test at 20 miles per hour, the deflection was only 0·42 inch, while the oscillation was almost infinitesimal, being at most 0·05 inch.

From the time the work was commenced in the building yard, the eighteen spans were erected and inserted in just under 10 months, or at the average rate of nearly two spans per month, while the whole work, including the breaking up and removal of the old girders from the bed of the river, was completed in 12 months. As regards cost, the work was carried out at a very economical rate. From arrival on the ground, including assembling, riveting, and getting into position on the piers, the cost was

£1 6*s*. 4*d*. per ton of new steel work, while the total work, including all temporary arrangements and plant, cost £3 15*s*. 4*d*. per ton of new steelwork. The riveting alone was completed at an average rate of 10*s*. per 100 rivets, against an estimated cost of 12*s*. per 100 if pneumatic plant had been used, as was at one time suggested.

Throughout the work there were no accidents of any kind, and with the exception of those caused by the outbreak of cholera, no fatalities. Mr. G. D. Mainprice, B.Sc., Assoc. M. Inst. C.E., was in direct charge of the work, and the Author's thanks are due to him for the assistance he has given in working out the details of the scheme, and for carrying the work through to such a successful conclusion.

The Author is indebted to Mr. J. T. Lewis, M. Inst. C.E., Chief Engineer, for permission to write this Paper, and to use the plans which accompany it.

The Paper is accompanied by a sheet of tracings, from which Plate 4 has been prepared.

(*Paper No. 4059.*)

"Branch Feeder-Lines in the Northern Orange Free State and Transvaal."

By Frederick Howell Rees, Assoc. M. Inst. C.E.

The question of suitable feeder-lines has engrossed public attention in South Africa for a long time, and during the last 14 years various lines have been built there to answer this purpose. Long before the Union in May, 1910, the Cape Government sanctioned two types of branch line, viz., 2-foot-gauge lines, and standard (3-foot 6-inch) gauge lines of the cheapest construction. The Natal Government also introduced 2-foot-gauge lines, but when this question had to be determined by the northern colonies, they decided in favour of standard gauge lines of the cheapest construction.

It cannot be claimed that either of the alternatives has been satisfactory, since any line constructed in a new country is certain to develop traffic, and as this development increases, the extra work and operating costs involved on the 2-foot gauge are very heavy. Transhipment at junctions becomes a heavy tax upon the working staff, particularly if the traffic fluctuates to any great extent, as there is then only sufficient staff detailed to cope with the work under normal conditions. As against this, however, the decreased cost of construction and the subsequent decreased interest charges are factors which cannot be overlooked.

On the other hand, it has been found that the standard gauge has cost a very much larger amount than the original estimate, owing to the necessity for substituting permanent bridges and culverts for the temporary wooden structures originally introduced, besides raising formation-level to prevent traffic being suspended during the wet season, generally strengthening the line, and laying down additional ballast; so that the cost eventually approximated to that of a first-class standard-gauge line, with which it could not even then be favourably compared.

Profiting by their own experience and that of other colonies in the past, therefore, the late Free State Volksraad, in December, 1909, sanctioned a line of railway from Bethlehem to Reitz and northwards, and also from Vrede to Klip River, as a means of developing parts of the country not served by the main trunk railways, whilst the late Transvaal Volksraad sanctioned the continuation of the latter line northwards from the Klip River to Standerton.

The preliminary survey of the Standerton–Vrede line was commenced in January, 1910, and was completed at the beginning of March, 1910, when the preliminary survey of the Bethlehem–Reitz line was commenced, and after completion of the first 10 miles, staking-out operations were undertaken, with a view to an immediate start being made with construction.

The country traversed may be described as undulating, as regards both lines, and although advantage was taken of the watershed as far as possible, the remaining portions of the two lines crossed the watershed, entailing more or less heavy work in banks and cuttings, and also at river-crossings. The length of the Bethlehem–Reitz line is 35½ miles, and the length of the Standerton–Vrede line is 44½ miles. As both lines are built to the same standard, it will only be necessary to specify the points where they differ.

Gradients and Curves.—The lines are laid out with maximum gradients of 1 in 50 compensated 0·04 per cent. per degree of curvature. The curves are set out circular up to 5° exclusive, but transition ends are introduced on curves of 5° up to 10°, which is the minimum curvature.

Earthworks.—The formation width of earthworks in embankments is 14 feet with side slopes 1½ to 1, whilst in cuttings the width is increased to 16 feet, with side slopes varying between ¼ to 1 and 1 to 1, according to the nature of the material encountered. Catchwater and table drains are of the usual standard dimensions.

Bridges over 30 Feet: Bethlehem–Reitz Section.—The principal bridges on this section consist of:—Three spans 20 metres, over Jordan River, 1 mile; three spans, 20 metres, over Liebenberg River, 4 miles; one span, 100 feet, and two side spans, 20 feet, over Tiger River, 19 miles; one span, 15 metres, at 29 miles.

It was anticipated that difficulty would be experienced in the first two bridges in obtaining suitable foundations within a reasonable depth, and it was therefore decided, particularly as the ground overlying the shale foundation was of a treacherous nature, to sink reinforced-concrete cylinders.

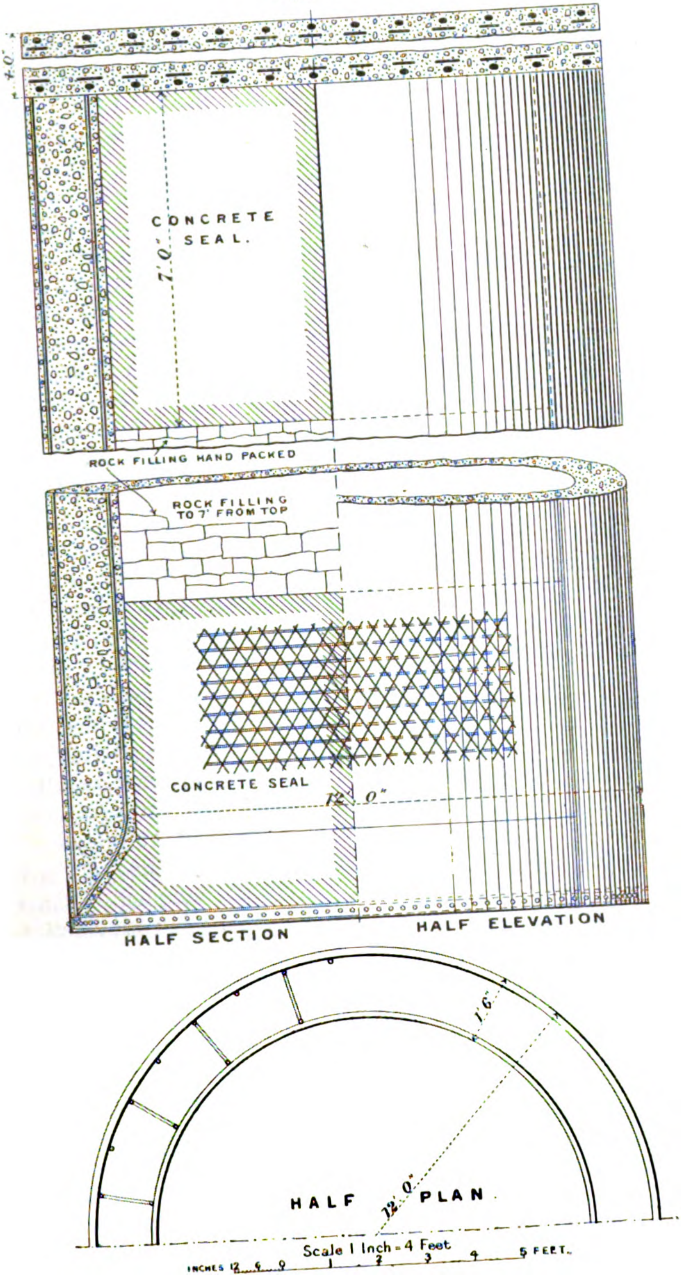
The cylinders consisted of an 18-inch ring of concrete, 12 feet in external diameter, reinforced with ½-inch iron rods on the outside and inside peripheries, and a triangular mesh netting, to which the iron rods were laced. The fitting or shoe forming the base of each cylinder was undertaken in Johannesburg, but was altered locally to meet requirements. Both the inside and outside casings were made from 6 to 8 feet long. The inside casing was constructed as one frame, but the outside casing was framed in three sections to facilitate removal after each operation, and each section framed in such a manner as to be easily unbolted or bolted as required. The shoe having been placed correctly in position, the inside casing was next transferred to its correct position, and the vertical rods secured to the shoe in the manner shown in *Figs. 1*, also the wire netting laced to the rods along the inner periphery as indicated. The rods along the outer periphery were then fixed, and the wire netting secured to them in the same manner. Finally the transverse lacing was done (*Fig. 2*), the outer casing bolted up, and the inner casing adjusted by means of a contractor's crane.

A temporary platform was erected, level with the top of the two casings, for greater ease in performing concreting operations, the concrete being loaded into skips, worked by crane, and deposited on a temporary platform, and from there shovelled into place. After a lapse of about 7 days from the time each section was concreted the outer casing was removed, the inner casing being held in position by means of an improvised overhead contrivance. Excavations inside the cylinder were then started, and during these operations the cylinder gradually sank to the required depth, corresponding with the lift intended, and each operation was repeated until good hard shale founding was obtained.

Great care had to be exercised in order to sink the cylinders perpendicularly, but this was accomplished satisfactorily, in spite of a few delays experienced in the earlier stages of the work, owing to running sand finding its way into the excavation through the sides. After each cylinder had been sunk to the solid, and it was seen that it had a secure bed all round, it was provided with a bottom seal of mass concrete 7 feet thick. Carefully-packed rubble stone was then inserted, and finally a top seal of 7 feet mass concrete. Concrete slabs 4 feet thick, reinforced with old rails, top and bottom, hexagonal in shape on piers, and oblong on abutments, as illustrated in *Figs. 1*, were built on the cylinder tops, and on this the neat work of the fitted rubble masonry was commenced.

At Tiger River, 19 miles, and at 29 miles, no difficulty was experienced with foundations, the rock being attainable at a reasonable depth. Good sandstone was procured throughout the route

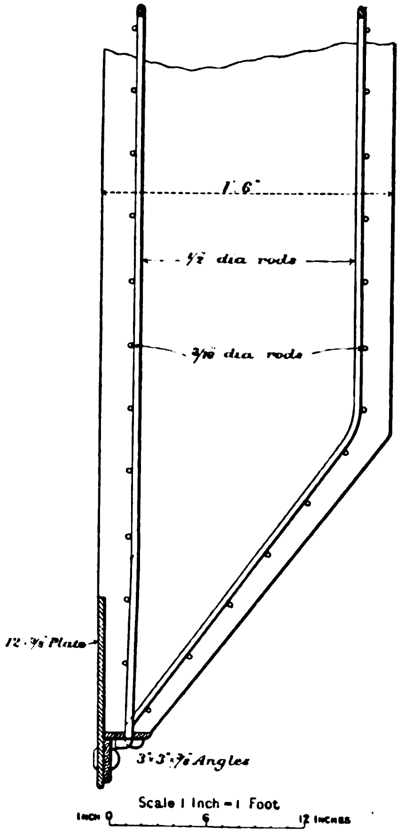
Figs. 1.


4' 0"
CONCRETE SEAL.
7' 0"
ROCK FILLING HAND PACKED
ROCK FILLING TO 7' FROM TOP
CONCRETE SEAL
12' 0"
HALF SECTION
HALF ELEVATION
1' 6"
HALF PLAN.
12' 0"
Scale 1 Inch = 4 Feet
INCHES 12 6 0 1 2 3 4 5 FEET.

suitable for building purposes. All superstructures consisted of second-hand material released from the main line, where the traffic became too heavy for the loads the girders were originally intended to carry.

Bridges over 30 Feet: Standerton–Vrede Section.—These comprised one span, 15 metres, at 3½ miles; one span, 10 metres, at 10 miles; one span, 10 metres, at 12½ miles; one span, 15 metres, at 16¾ miles; two spans, 30 metres, and two side spans, 15 metres each, at Klip River, 18¾ miles. The work performed in the first four bridges needs no special reference.

Fig. 2.



At Klip River the excavations for the three piers were taken down to rock, but the abutments were treated in the same way as the Jordan and Liebenberg bridges on the Bethlehem–Reitz line, by sinking concrete cylinders 14 feet in diameter instead of 12 feet, and the same method of sinking was adopted. Concrete was, however, substituted for masonry on this line, except at the Vrede end, owing to the quality of the stone being too inferior for the purpose. Dolerite stone was plentiful, and this was used for all concrete work.

The superstructure for the Klip River bridge consisted of released material from the main line, but was considerably strengthened at joints by the insertion of numerous gusset plates during the process of erection. Falsework was erected on the completion of the substructure, on which the steelwork was run out in sections and erected. All other superstructures were similarly second-hand, released from the main line.

Culverts.—The type of culverts varied to suit the conditions of each case, but were for the most part covered concrete tops, reinforced with old rails and rods for spans of over 6 feet, whilst several arched culverts were introduced wherever they were warranted. The construction of these culverts was of the highest class of workmanship.

Permanent Way.—The permanent way consisted of second-hand 60-lb. rails of the Vignoles type, fished up with angular fish-plates, both released from main-line service. The rails were laid on steel sleepers of keyed type, except at joints, where steel-post sleepers had to be used.

Ballasting.—The ballast used was decomposed ironstone, obtained in close proximity to the works, and the quantity represented 1,400 cubic yards per mile, the depth of ballast under the sleeper being 4 inches.

Stations and Sidings.—The accommodation at stations and sidings was restricted as far as possible until it was known what additional accommodation would be warranted by the traffic, but on both lines a station-building of stone was erected at each terminus with staff-quarters, a goods-shed of wood and iron, a stone-faced platform surfaced with gravel, a cattle-kraal of old rails, and the usual offices. The sidings at intermediate points occurred at intervals varying between 6 and 10 miles, and consisted of a wood and iron shelter for passengers, crossing loop and spur, alongside which a wagon-landing was erected. A triangle was also constructed at each terminus.

Water-Supplies, Bethlehem–Reitz Section.—A gravitation supply was inaugurated at Reitz from a source about ¾ mile from the station, where a natural fountain existed. A cement storage-tank of 50,000 gallons capacity was constructed in close proximity, into which the fountain water was led by conduit, and the supply then gravitated through a 4-inch spigot-and-socket pipe to the engine parachute tank at the station. The domestic supply is obtained from a 6-inch bore-hole, about 75 feet in depth, in the vicinity of the quarters; the water is stored in a wooden tank of 1,800 gallons capacity, into which it is pumped, and from which it gravitates into the houses through 1-inch galvanized pipes.

Water-Supplies, Standerton–Vrede Section.—The first supply is at Klip River, where the water is pumped from the river by means of a 6-HP. steam-pump and boiler, to a siding site immediately adjacent to the south bank of the river, and forced into a 20,000-gallon overhead cast-iron tank, from which the engines obtain their supply direct.

The second supply is at Vrede, but although the town agreed to give the administration a connection with their town main, there was no water available from this source when the time arrived, and consequently temporary arrangements had to be made until the town could fulfil its obligations. A 50,000-gallon cement storage-tank was therefore erected above the station-site in such a position as would permit the water to gravitate into it from the town main eventually, and at a sufficient elevation to admit of its gravitating into the engine parachute tank at the station, whilst a well was sunk near the spruit opposite the storage-tank and built up above flood-level. A 6-HP. pump and boiler were then installed, and, as a temporary measure, the water was pumped through a 4-inch galvanized-iron pipe into the storage-tank.

Fencing.—The fencing consisted of a six-wire fence, 4 feet 3 inches high. Straining-posts of old rails are fixed every 220 yards apart and Lochrin standards intermediately every 33 feet. 14-foot iron gates are provided at farm-road crossings and open cattle-ditches at main-road crossings, to which the fence was connected, two being provided at each main crossing.

Telegraph.—A two-wired circuit was provided the whole length of each line, furnished with telephones in the intermediate shelters for the convenience of the public.

Cost.—The cost of the Bethlehem–Reitz line was £4,158 per mile, and of the Standerton–Vrede line £4,373 per mile.

Labour, etc.—The labour employed for earthwork on both lines was European labour in butty gangs of about ten men, and they were paid according to the following schedule:—

	Per Cubic Yard.				
	s.	*d.*		*s.*	*d.*
(*a*) Earth, sand, loam, or gravel	0	8	to	1	0
(*b*) Loose rock, hard gravel, soft or rotten shales, and boulders under 2 cubic feet	1	3	,,	1	4
(*c*) Every variety of soft, loose, or thinly-bedded rock, small boulders in hard clay, hard or strong shales, soft or laminated sandstones, ironstones, or other similar material	1	6	,,	1	9
(*d*) Hard, sound, massive sandstones, conglomerate, and gravel rocks, which in the opinion of the engineer require blasting, and does not come under head (*c*)	..			2	6
(*c*) Whinstone and other solid rock not included in the above . . . . from	..			3	6

The prices include 200 feet barrow lead and 500 feet track lead, free. The track was supplied free by the administration, extra lead being according to arrangement.

	Per 100 Feet. *s.*
Forming light work up to 12 inches, classes (*a*), (*b*), (*c*)	25
,, ,, 12 ,, ,, (*d*), (*c*)	40
,, ,, 12 inches to 18 inches, classes (*a*), (*b*), (*c*)	45
,, ,, 12 ,, 18 ,, ,, (*d*), (*e*) .	60

For plate-laying and ballasting operations native labour under contractors was employed, as the Europeans did not work satisfactorily in large gangs. Building operations were also conducted on the same lines. Cement was at all times supplied by the administration to the contractors, and the price per cubic yard for masonry averaged 32*s.*, and for concrete 25*s.* Native labour was obtainable by contractors for unskilled work at 2*s.* 6*d.* per day, and European artisans at 20*s.* per day.

Rolling Loads.—The heaviest engine permitted on both lines is known locally as a "seventh-class" locomotive, having a total wheel-base of 46·16 feet and weighing, when full, 87·39 tons; the weight of the heaviest driving-axle is 11·125 tons.

Completion of Works.—The Bethlehem–Reitz line was handed over to the transportation department on the 2nd December, 1911, and the Standerton–Vrede line on the 1st May, 1912.

Conclusion.—The two lines of which the foregoing is a brief description are considered secondary lines; that is to say, they are intended as feeder-lines in the first instance, but may at some future date develop into important through lines, suitable for main-line traffic, as soon as the development of the districts traversed by them has sufficiently advanced, and they are fully connected. Until this period arrives, the policy is to construct a substantial road-bed, with bridges and culverts, which would answer for the heavier traffic when the time arrived, but meantime to economize in every other respect.

The Author acted as Divisional Engineer on the works described, and is indebted to Messrs. A. M. Tippett and M. D. Robinson, MM. Inst. C.E., Engineer-in-Chief and New Construction Engineer respectively, for permission to publish these notes.

The Paper is accompanied by a map and one sheet of tracings, from which the Figures in the text have been prepared.

(*Paper No. 4070.*)

"Some Public Works at Kuching, Sarawak."

By HARRY FREDERICK CAREW-GIBSON, M. Inst. C.E.

(*Abridged.*)

THE territory of Sarawak, which is ruled by Rajah Sir Charles Johnson Brooke, G.C.M.G., originally extended for some 400 miles along the north-east coast of the island of Borneo, being bounded on the north-west and south by Dutch territory, and on the north-east by Brunei. It has now been extended south and east of Brunei by further concessions and by purchase until it meets that of British North Borneo at the Lawas River. The area is about 50,000 square miles, and it contains a mixed population of 600,000, composed chiefly of Malays along the sea-board, and of Dyaks, Kayans, Muruts, Chinese, and other native tribes in the interior and on the various rivers.

The town of Kuching, having a mixed population of 24,000, situated on the Sarawak River, about 12 miles in a direct line from the sea, is the capital and seat of government. Communication is maintained with Singapore, 440 miles distant, by two steamers of 893 and 903 tons burden, owned by the Sarawak and Singapore Steamship Company, which make weekly trips to and fro throughout the year and carry the mails. The same company also own other steamers which carry the bulk of the coasting trade.

REINFORCED-CONCRETE TANK.

The water-supply of Kuching is derived from Matang mountain, and was inaugurated in 1907. In the following year it was determined to build a water-tower to supply the higher portions of the town, the old service-reservoirs situated at an elevation of R.L. (reduced level) 105 being incapable of so doing. There being no higher ground available, the tower was designed to stand near the existing reservoirs on ground at R.L. 103, with its floor (at an elevation of 51½ feet) at R.L. 154·12, the total height of the structure from ground-level to finial of roof being 83 feet. Estimates were obtained in England for such a tank both in cast iron and steel (see Appendix); but taking into consideration the climate (which is a very humid one, with an average annual rainfall of 160 inches), first cost and upkeep, the Author decided to recommend the construction by the Public Works Department of a reinforced-concrete tank.

The design adopted was for a circular tank of 30 feet internal diameter and 16 feet deep, to hold 70,000 gallons, standing on a braced structure of reinforced concrete. This consisted of three central vertical legs grouped in the form of an equilateral triangle connected at the summit by three semicircular arches of 5 feet 9½ inches clear span, and six battered (1 in 40) legs of like section (18 inches by 18 inches) situated at the apexes of the enclosed hexagon, connected at their caps with one another and with the three central legs by reinforced-concrete girders. These again carried six radial members (built flush with them), extending from the central legs to the circumference of the tank at the centre of each chord, the latter members being designed partly as girders and partly as cantilevers; the whole supporting the floor, consisting of a concrete slab 8½ inches thick reinforced with No. 68 expanded metal. Two 9-inch diameter flanged cast-iron pipes are led into the bottom of the tank in its centre, one being the rising main, which also acts as the delivery, finishing flush with the inside of the bottom of the tank in a stuffing-box formed to receive it, and the other being carried up through a stuffing-box to water-level, and acting as an overflow into the old service-reservoirs.

A "billian" (local iron-wood) roof of umbrella type braced with iron rods was built to cover the tank, a ventilator was formed in it near the top, and an entrance or manhole was also left in the roof, from which an iron ladder was carried to within 18 feet 6 inches of the ground; a lightning-conductor is fitted at the top of the roof, and a cable is carried down from this and well earthed. The water-level is shown on a gauge affixed to the outside of the tank. The estimated cost was $8,980.

Foundations.—The foundations being in soft white clay, it proved necessary, after going down 6 feet, to drive "baku" piles at 2-foot centres (this timber is practically everlasting when buried), and sixteen of these piles 12 feet long were driven under each leg by hand with a heavy timber dolly. They were then capped with concrete, which was, in the case of the six outer legs, 8 feet by 8 feet, reducing by means of steps (Figs. 1, Plate 5) to 4 feet 2 inches by 4 feet 2 inches at ground-level, with ornamental pilasters 2 feet 8 inches by 4 feet high forming the base of each of the outer legs. The foundation for the three inner legs was of the same construction, except that the equilateral triangle in the centre was filled with concrete, forming a foundation for the supply and outlet pipes. It will be seen from the Figure that the 9-inch inlet or rising main also acts as the outlet, and by means of a tee-piece, valve, and reduction piece, is connected with a 6-inch high-pressure main.

Legs and Braces.—These are of rectangular section with the corners chamfered so as to avoid sharp arrises, which are objectionable in concrete work. For the legs, eight $1\frac{1}{2}$-inch mild-steel rods are used as reinforcement, and these are bound together by $\frac{3}{16}$-inch wire wrapped round them spirally at a pitch of 3 inches, forming a cylinder 1 foot 3 inches in diameter, and are tied together about every 3 feet diagonally with wire. The same construction is used for the 6-inch by 6-inch struts and ties, only that four $\frac{5}{8}$-inch rods were used. Care was taken that the main reinforcement rods, where jointed, broke joint, and these joints were made with screw collars and the main rods were reduced to $1\frac{1}{4}$-inch diameter after the first stage was passed. All the steel reinforcement was covered with at least $1\frac{1}{2}$ inch of concrete. It was erected in situ and kept well ahead of all concreting work, being given a brush wash of cement as soon as completed.

The steel skeleton was carried up well above the first system of bracing before the timber moulds were placed and the concrete poured. The forms for the legs were three-sided boxes made of native timber of various lengths, with battens round them and bolted together, one side being closed with short boards as the concrete filling proceeded, thus making it possible to tamp it well in the forms and so ensure clean and dense concrete. The steel reinforcement was then continued above the second bracing when the forms were unclamped and moved upwards, and so on until the springing of the arches or the capstones were reached.

An ordinary scaffolding of native timber was employed to support the timber forms used in forming the floor-girders and as a platform for the workmen. All the concrete was hoisted into position by ropes and buckets, the mixing-stage being situated on the ground under the tower. Hand-mixing was employed until the forms were in position for the floor of the tank, when a 6-HP. Smith mixer was used.

The reinforcement of the floor proper consisted of No. 68 expanded metal; this was overlapped two meshes wherever a join occurred, and was bent up round the sides of the tank so as to form a key to the reinforcement of the tank-walls. The expanded metal was laid upon the timber floor forms, and concrete was spread over it to the depth of about 2 inches. It was then lifted by men with iron hooks and well shaken, so as to allow the concrete to settle under it, the filling of the concrete proceeding all the time. Care was taken to consolidate the aggregate by ramming, the top surface being purposely left rough to form a key for the plastering.

The reinforcement of the sides of the tank consisted of No. 68 expanded metal for two-thirds of the height and of No. 62 for the top third, all wired together and given at least 6 inches of overlap at the joints of the sheets, which are placed in the centre of the thickness of the wall, and are again strengthened against bursting-pressure by two mild-steel hoops of 2 inches by ½ inch section placed at 3 feet and 7 feet respectively above floor-level. Near the top of the tank some ⅜-inch steel rod was used in place of No. 62 expanded metal, of which a shortage occurred.

The timber forms for the exterior were made in sections 5 feet to 6 feet long and 6 feet deep for the first ring, and 5 feet deep, with two timber runners accurately shaped to the radius, the planking being 1½-inch native timber planed and jointed. Enough was made to form when bolted together a complete shuttering round the tank to its full height. Telegraph-wire was used to tie these to the internal moulds, which were made of 1½-inch boards on end reaching the full height of the tank, and fastened to timber battens formed of two-ply 2-inch boards shaped accurately to the internal radius, and secured to a rough scaffolding erected on the tank-floor.

The three semicircular arches connecting the centre legs are monolithic, and were formed in timber box-moulds with imitation voussoirs. The six girders spanning the space (11 feet 11 inches between centres of bearing) between the outer legs of the tower and the centre arches are reinforced with four ⅝-inch diameter mild-steel rods (except for 3 feet 1 inch in the centre of the span, where there are six) to provide for tension; ⅝-inch diameter rods at 12-inch centres are wired to these and bent up at an angle of 45° to resist shearing stresses.

The six stiffening members, which are carried by the centre arches and the exterior girders, are in part girders and in part cantilevers, and to meet the stresses in these, four ⅝-inch diameter mild-steel rods are provided on the tension side of the member (crossing over at 45° where the stresses reverse), and a sheet of No. 68 expanded metal set on edge in the centre of the member, and extending to within 2 inches of its full depth on either side.

The six girders spanning the space between the outer legs of the tower, which is 14 feet between centres, are reinforced with a piece of 4-inch by 1¼-inch flat bar steel situated centrally and within 2 inches of the lower face. These bars are drilled at 1 foot centres, except for the middle 3 feet 1 inch, and ¾-inch diameter rods bent at 45° are threaded and bolted to them to take up the shearing stresses.

The moulds used consisted of 1½-inch planks on end for the inside shuttering the full height of the tank, and these were nailed to timber forms of 2-inch plank cut to the correct radius, breaking joint in two thicknesses, and bolted together. The forms were spaced vertically at 6 feet centres and supported by struts from a rough timber staging erected upon the floor of the tank, as previously explained. The external forms were for the first ring 6 feet high and 5 feet or 6 feet long and were carefully planed, but no oil or other dressing was used on them; they were stiffened with two plys of 2-inch timber cut to the radius and breaking joint, two of these being used on each form; the planking was 1½-inch native timber. The two top rings were only 5 feet high, but otherwise were constructed in the same manner as the lower ring of shuttering.

Wall-plates of 5-inch by 5-inch billian timber were laid on the top of the walls of the tank to support the roof, and fang-bolts were embedded in the concrete at 4 feet centres to secure these. All the work was kept well covered with old sacks and native palm mats ("kajangs") to protect it from sun and rain. The interior of the tank was scratched while yet green, to afford a key for the plastering, which was put on in two coats by Chinese masons with wooden floats.

The aggregates used were crushed stone (quartzite) from the Government quarry at Sijinkat, up-river sand taken from a sand-bank beyond the reach of salt water, and Portland cement supplied in barrels containing 3·2 cubic feet. They were in the following proportions:—

For the foundations a 1 : 3 : 5 mixture was used.

For the legs, bracing, and sides of the tank a 1 : 2 : 3 mixture was used.

For the internal plastering of the tank, "aquabar," mixed in hot water in the proportion of 1 part "aquabar" to 36 parts by measure of hot water, was used with 1 part cement and 2 parts fine sand; but an alum and soap solution was afterwards substituted for this, consisting of 4 lbs. of sulphate of soda to 12 lbs. of soap and 400 lbs. of water, mixed at 112° F. These mixtures, however, are of doubtful efficacy as waterproofing mediums, for which hydrated lime or oil might prove more suitable.

The tank was completed on the 24th December, and was gradually filled with water, being completely full by the 29th December, 1909.

The tank started sweating after standing with 6 feet of water in it for 4 days, and three or four drips began, but most of these took up, though one or two faulty places remained, which in every case were situated in the walls of the tank at the junction of one day's work with another. They might have been avoided by completing the walls of the tank in one pouring of concrete. It was decided, after the tank had stood with water in it for 1 month —during which time it had lost 6,000 gallons—to empty it for inspection, and this was done gradually. It was found that in two places the internal plastering was faulty, not being solidly attached to the walls. This was accordingly cut out and renewed, and the whole of the interior was given two coats of neat cement wash laid on with a stiff brush. These repairs, costing $321·66, were completed and the tank refilled on the 26th March, 1910. It was handed over to the Waterworks Department on the 7th April, 1910. It was put at once into regular service, and up to the date of this Paper (December, 1912) had remained quite tight, and required no repairs.

The calculated weight of the structure, including the concrete in the foundation, was:—

	Tons.
Concrete in foundations	193·91
,, pedestals to legs	19·70
,, legs, braces, struts, floor-girders and plinth and the walls of the tank	263·70
Total weight of concrete	477·31
Steel in the form of expanded metal	3·70
,, ,, rods, wire, etc.	8·90
Approximate weight of the roof	7·00
,, ,, iron ladder, etc.	0·30
Total weight empty	497·21
Add weight of water	299·09
Total weight on foundations	796·30

Note.—The approximate area of the foundations is 730 square feet.

Tank empty = 496·91 tons, or $\frac{496 \cdot 91}{730}$ = weight per square foot on foundations = 0·6806 ton.

Tank full = 796 tons, or $\frac{796}{730}$ = 1·09 ton per square foot on foundations.

The weight of 1 : 2 : 3 concrete being taken as 143 lbs. per cubic foot, the average weight of 1 : 2 : 3 concrete with reinforcement = 149·7 lbs. per cubic foot.

The weight of steel and iron used was, for reinforcement, 12·6 tons, and the weight of the roof was estimated at 7 tons.

In the design of the reinforcement the tensile stress for the steel, or f_s, was taken to be 15,000 lbs. per square inch, and the safe compressive stress for the concrete, or f_c, was taken at 600 lbs. per square inch, the tensile strength of the concrete being neglected.

The actual cost of this tank after testing, including the repairs mentioned, is given in Appendix I, together with the estimated cost of a cast-iron tank of similar elevation and capacity for purposes of comparison. It will be seen that the reinforced-concrete tank works out $1,926·94 cheaper in first cost, and will undoubtedly cost little or nothing for upkeep, whereas in this climate the cost of painting an iron tank would have been a heavy annual charge.

THE BROOKE DRY DOCK (Figs. 2, 3 and 4, Plate 5).

The construction of a graving-dock capable of taking any steamers frequenting the port of Kuching was resolved upon in July, 1908. The Sarawak River, at the site reserved by the Rajah for the dock, makes a sharp bend to the north-west and is 660 feet wide. It is subject to tidal influence, and the stream is only slack for a period of about ½ hour at the turn of the tide, attaining at other times a velocity of about 6 knots. The banks are of earth, showing some mud at low water. The river always has soil in suspension, and during the wet season, or north-east monsoon, the fresh water in "spate" often masters the flood-tide, so that vessels moored in the river at such times have been known not to swing with the tide for periods of over a week at a time, though this is unusual.

The highest known flood was R.L. 27·25, and the lowest R.L. 8·00. The mean range of tide is 10·59 feet.

As economy in construction was of first importance, the Author decided to recommend a tidal dock, to be constructed of concrete, with its sill at R.L. 12·66, which is mean low-water level, and its floor (a flat one) at R.L. 10·00, length on the floor 240 feet from the inner side of the sill, and width at entrance 40 feet at sill-level and 45 feet at coping-level, which is R.L. 28·00.

After some study, it was decided to build the side walls in seven steps or altar courses, the chief reason for this decision being that it was anticipated many quite small steam-launches would use the dock and that the same moulds could be used for all the face-blocks. A ship-shaped steel caisson-gate, with centre slapping keel and water-ballast tanks, was to be used for closing the entrance, chiefly because this form reduced the amount of masonry required at the entrance and because of the difficulty of obtaining the hollow quoins that would have been necessary if gates had been adopted.

One dolphin was provided on the up-stream side and a fender-pier 60 feet long on the down-stream side (to which the caisson is moored when the dock-entrance is open), both of reinforced concrete. A small pumping-plant for dealing with the seepage and rain-water and any water not draining out with the tide was provided for.

Borings were put down, and showed hard shale at a suitable depth for the foundations. Rough drawings were prepared, and the estimated cost of the work on these lines came to $70,000.[1] Situated just up-stream of the dock is a short length of retaining-wall supporting a 15-ton steam swivelling-crane, which is used for lifting masts and boilers from vessels. It was necessary to make good the bank between this and the dock with a retaining-wall, but neither this work nor the pumping-plant was included in the estimate for the dock.

The work had to be carried out by the Public Works Department labour force, supplemented by some Chinese and Javanese coolies, and the rate of progress was limited by the money available from time to time, the work being at one time (January–September, 1909) completely stopped.

The dock has a curved inshore end, the floor being flat in the centre for a width of 6 feet, and 2 inches being allowed for discharge from the centre to the side drains, which are at the toe of the side-walls and sill, and are given 1 foot of fall from the inshore end (where their invert is at floor-level) to the sill; they drain into a sump, which connects with the well by means of a 2-foot culvert. A 12-inch cast-iron pipe with valve situated in the well forms the inlet and outlet, supplemented by a 9-inch valve in the gate. All valves have rods carried up to coping-level where they are operated by ordinary turnkeys, which are removable. There are two flights of steps formed in the concrete splay-walls on either side near the entrance, and nine timber slides are provided, four on either side, and one which has concrete steps on either side of it at the extreme inshore end of the dock. The plant available for constructional purposes consisted of one small 3-foot-gauge locomotive with fifteen side-tip trucks, rails, etc., one 6-HP. Smith concrete-mixer, three Scotch derricks with steam winding-gear safe for 3 tons, with skips, etc., one 30-cwt. steam swivelling-derrick and two piling-engines. "Tongkangs" or lighters of from 15 to 50 tons burden were available from the Government quarry at Sijinkat. A gravity concrete-mixer and a small turn-table were built in the Government workshop, and proved very useful.

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[1] This estimate was for a dock only 200 feet long and closed at its inshore end by a timber coffer-dam.

There being no freestone or granite available locally, it was decided to complete the whole in concrete and to form the bulk of the facework as moulded stones set in courses. Thus all the stones in the bull-noses were moulded; the sill-stones and jambs, and the whole of the dock-walls and altars were faced with moulded blocks set in courses and backed with concrete in mass. The floor, splay-faces and steps at the entrance and the timber slides are monolithic.

The opening closed by the caisson has a batter of 1 in 16·84. The slapping face is 15 inches wide and a groove is formed in the sill with wedge-shaped outer face, and slides 2 inches by 2 inches of wrought iron are let into this at 2-foot centres and stand up 2 inches above the concrete. On these the timber keel of the gate slides as it sits into the groove, and by this wedge action is held up tight to the slapping face of the sill. The groove has a clearance space to allow any small stone or other obstruction to fall clear of the gate; any mud entering the groove is forced out along the 2-inch space formed by the iron slides; provision has been made for cleaning this groove by means of a 1½-inch pipe led into it and connected with the town water-supply; but at low tides this can generally be cleaned out by hand. Eight cast-iron bollards are provided, four on either side, set back 1 foot 8 inches from the face of the dock, and six heavy timber (billian) bollards or mooring-posts are provided, three on either side of the dock and set back 30 feet from its face. Two hand-winches (one on either bull-nose), with ⅞-inch diameter wire rope and the necessary sheaves for hauling the gate open or shut, are provided. Recesses are formed in which to house the two turn-buckles, which are provided for holding up the gate to its slapping face 2 feet 3 inches below cope-level.

Caisson (Fig. 4, Plate 5).—The caisson-gate is constructed of steel, and was built by Messrs. Howarth Erskine and Company, Ltd., of Singapore, who were entrusted with the design of the structural details to fulfil the Author's requirements. It is of ship shape with a central slapping keel fitted with hardwood ("penyau," or local greenheart) slapping timbers, these being grooved to contain a 1-inch diameter tarred rope, which is caulked into it and stands out a full ¼ inch, so as to make a water-tight joint with the dressed concrete face when the pressure comes on. The caisson is divided by bulkheads and a steel stepped deck (fitted with manhole, ladders and air-valve) forming a tank for water-ballast, which is used for sinking the caisson when in position, a 6-inch inlet-valve being provided for this purpose, which is opened or closed from the deck of the caisson by means of a removable key.

The top deck is of $\frac{1}{4}$-inch steel plate overlaid with tarred felt and 2-inch penyau planks, which are caulked. A folding hand-rail is fitted, consisting of light iron stanchions which fold inwards and carry a chain swung between them. Two 6-inch by 6-inch penyau timber rubbing-pieces are fitted on either side of the caisson, being bolted to light angle-bars riveted to the skin of the caisson for this purpose; mooring-irons are fitted at either end.

As built the caisson weighs about 39 tons, and with 21½ tons of concrete ballast draws 9 feet of water and is stable at any angle of heel. The lower part of the tank has a capacity of 12 tons of water-ballast and the upper off-set of the same tank (which was provided to bring pressure on to the upper part of the slapping faces by tending to tilt the gate inwards when full) holds another 5 tons of water-ballast. In practice it is found that the gate is reasonably tight without making use of either the off-set tank or turn-buckles; its draught is increased 2 feet by the filling of the lower tank only.

The contract time for delivery of the caisson was 20 weeks, but owing to delays and alterations this was considerably exceeded: it arrived in Kuching on the 20th April, 1911. Pending the arrival of the Chinese riveters and erectors, the steelwork was unloaded into lighters and transported to the dock. Timbers were placed on the inner sill and the gate was erected on them at a slight angle to the sill. Before the riveting was completed it had become apparent that the keel was not straight. During the Author's absence in England the slapping timbers were fitted and the gate jacked into position and tested, this being done under contract by Messrs. Howarth Erskine, whose representative had sole charge of this work. On the Author's return work was accordingly hurried on, and as the concrete work of the dock had been almost completed, it was decided to float out the caisson and test it. On this being done it was found that spun-yarn had been used on the slapping face instead of a tarred rope inset, and the gate had sprung so that on reclosing it the leakage was very bad. It was therefore determined to dock the caisson and correct the timber slapping-pieces by packing them out with tarred felt introduced between the steel and the timber in those places which had been marked as leaking badly. This work was done at low water by the Chinese carpenters employed by the Public Works Department, the bolts were tightened up again, and a groove was cut extending all round the timber slapping face 3 inches from the outer edge of these timbers (so as to leave room for a second packing-rope if necessary). Into this a tarred rope was caulked by hand and allowed to stand up a full ¼ inch. The gate was then undocked and floated into position, and after one or two adjustments it proved quite tight. Although it has been opened and closed about twelve times since, nothing more has been done to the slapping face, the seepage and leakage amounting only to about 1,000 gallons in 24 hours in dry weather and perhaps twice that quantity in wet weather.

A small concrete well covered with a grid is built over the end of the 12-inch pipe and is carried up to sill-level so as to be clear of the mud, and this pipe has a common inlet and outlet formed in deep water by a billian box-drain which enters the well at the same level as the pipe; this is situated clear of the entrance and is buried in the ground and anchored to short billian piles driven a few feet into the earth. A 9-inch valve has since been fitted in the centre of the caisson to assist in filling and emptying the dock. The centre-line of the dock was pegged out and the coffer-dam was commenced in August, 1908. A single line of timber sheet-piles was driven to form a coffer-dam where the natural bank left in was not considered strong enough. While this was going on a railway was laid from the head of the dock along the road for a distance of about 1 mile to the tipping site. As soon as possible an incline road was run down into the dock-bottom and the excavation started, the locomotive hauling the trucks up by means of a steel rope and snatch-block when the incline became too steep for it to climb. It was decided not to sink timbered trenches for the walls, but to use strutted walings with poling-boards, and to take out the whole of the excavation in short lengths to foundation-level, beginning at the river end. This permitted the concrete floor to be put in, and extended under the side walls in short lengths without a longitudinal joint, as soon as the hard shale bottom was reached. It was found that 5 or 6 feet could be got in in this way during a day's work. Care was taken not to leave the surface of the shale exposed longer than necessary, the last 6 inches of the excavation being taken out within 24 hours of the depositing of the concrete. Sumps were formed where necessary as the work proceeded, and were, as a rule, sunk under the side walls. For the greater part of the time two 3-inch pulsometer pumps were found sufficient to deal with the water. No blasting was necessary, except for the curtain wall and permanent sump, which were founded on hard black shale. Only light charges of gelignite were used to avoid starting cracks in the shale; this work was carried out by Malay workmen from Sijinkat quarry.

On the 30th November, 1908, the sheet-piling near the entrance on the east side of the dock, which had been driven because the bank here was considered weak, developed a serious leak under the piles, which were found to be resting on a mattress formed of old shavings and timber refuse. As they could not be driven through this, the sheet-piling was carried farther along the river-bank in the line of the coffer-dam and clay was dumped behind it, effectually cutting off the seepage from the river at this point. On the 23rd January, 1909, the poling-boards on the right-hand side of the dock were driven in, owing to excessive pressure caused by a heavy rainfall; this was repaired and the weight of earth lightened. On the 6th February a further slip occurred and more lightening had to be resorted to. On the 1st March, 1909, during the night the river rose very rapidly to river-level 27·00 (i.e., 2 feet 10 inches higher than the previous highest water recorded), topping the coffer-dam and flooding the dock excavation; this was the most serious mishap met with during the 3 years that the dock was under construction and took 6 weeks to repair. The sheet-piling, where damaged, was drawn and redriven, extra walings and struts fixed, and about 2,000 gunny bags three-quarters full of sand were built up to R.L. 28·00 on the outside of the sheet-piling. More clay was then tipped on the crown of the coffer-dam, so that work was able to proceed again towards the end of April. No further mishaps of any consequence occurred.

The first concrete deposited for the floor of the dock was in No. 3 section. This was put in on the 25th January, 1910, and consisted of a length of 6 feet, the full width of the dock, including the thickness of the side walls, i.e., 56 feet 3 inches. From this time until the end of the year the work progressed without incident up to section No. 25; the sill, bull-noses, sump and well, and a considerable portion of the dock-walling, as well as the floor, were completed. From section No. 25 bad ground was encountered, the shale dipping away rapidly towards the head of the dock, and heavy timbering with two rows of king-piles and struts had to be resorted to to prevent the dock road coming in. From this point up to the springing of the arch forming the head of the dock the walls were increased in thickness.

Evidently an old creek connecting the Sungei Gertak had once existed here, as the remains of piles such as natives build their houses on were found in the mud overlaying the shale, and much water and mud came in on the down-stream side of the dock, causing some settlement which was afterwards made good.

The solid shale was not reached here until a depth of 16 feet below floor-level was attained. Large displacement stones were used liberally, with the object of economizing cement, in all concrete deposited in mass, in the floor of the dock or elsewhere. All the stone used came in lighters from Sijinkat quarry, which is about 12 miles below Kuching and is worked by the Public Works Department. The stone from this quarry is a hard quartzite rock, and the actual cost price of the stone was charged against the dock. All the cement used was imported from Singapore.

Relief-holes about 2 inches in diameter were left wherever necessary in the dock-floor; generally two in alternate sections were required, and were formed by the use of bamboo, which rotted after a few months and was then easily split up and removed. These relief-holes were left open until the completion of the dock, when they were gradually closed by careful grouting with liquid cement under pressure, working from the river end of the dock.

Special moulds were made for the bull-nose stones, which were bedded in cement mortar in seven courses, one set of moulds serving for two courses. The special stones forming the jamb for the sill are 2 feet 3 inches deep by 3 feet 7½ inches by 1 foot 6 inches, care being taken in moulding these to use 3 inches of fine stuff on the slapping-face, which was axed and rubbed down true after they were set. The inner sill is formed of stones 3 feet by 1 foot 6 inches by 1 foot 6 inches, set in cement mortar on concrete in mass and breaking joint both vertically and horizontally. The jambs are treated in the same way, but are formed of larger stones. The altars are formed of stones 2 feet 6 inches by 1 foot 3 inches by 1 foot 3 inches with a chamfered edge, 3,216 of these being required.

The retaining-wall previously referred to on the up-stream side of the dock was completed and the ground behind it was reclaimed before the dock was opened. This wall, which is 91 feet long, is of dry stone, founded upon two rows of concrete blocks resting on hard clay, and is coped with cement flags; it was completed for $1,020, or $11·20 per lineal foot.

A buoy with mooring-chain was anchored 300 feet from the dock on the centre-line of the entrance; this is intended for vessels to moor to while awaiting the tide to enter the dry dock. Any large vessel entering would make fast to this mooring, and at slack water of high tide send her bow ropes ashore and attach them to the bollards at the dock, and then haul herself in by her own deck-winches.

The Fender Pier and Dolphins.—In the construction of these reinforced concrete was used, and the steel reinforcement in most cases consisted of old rails, weighing about 11 lbs. to the yard, and ¼-inch binding wire. The reinforced-concrete piles were moulded horizontally in hexagonal timber moulds, and were generally 21 to 26 feet in length, the reinforcement terminating in an iron shoe, except in a few cases where shoes were dispensed with and the rails forming the longitudinal reinforcement were bent to a point.

The method adopted in making the piles was to make small wooden templates of 1-inch board with notches cut in them to take the longitudinal reinforcement, which generally consisted of four old rails of light section, or, in some cases, of six ¾-inch or 1-inch diameter steel rods. These were held together temporarily with a wire lashing, templates being introduced wherever necessary to prevent sagging and to keep the correct spacing. One end was then bent in and housed in the pile-shoe, which was attached with wire, and the whole was wrapped round by hand with ¼-inch iron fencing-wire at about 3 inches pitch, the winding being kept in place by light binding-wire. This steel skeleton was quite rigid and was placed in the timber mould and centred in it by supports at either end. The mould was then closed except for the top board, and the aggregate was poured and well rammed. The piles were left in the moulds on an average 8 days, but were not moved or driven under 4 to 6 weeks' time. In most cases holes were got out 2 feet or 6 feet deep at low water in the red clay overlaying the shale, and the piles were then driven with a 30-cwt. monkey as far as they would penetrate. The heads of the piles were not protected in any way while being driven, as it was necessary to bring them to their correct length by splicing the reinforcement, encasing their heads with moulds, and pouring concrete to the correct height, so that some concrete had to be removed by chisel and hammer before the joints could be made.

The longitudinal and transverse runners or beams were formed in timber moulds in situ, anchor-bolts being left in where necessary to hold the wall-plates to which the penyau timber floor is treenailed.

The timber rubbing-pieces are of 6-inch by 6-inch billian timber, strapped to the piles with iron straps fitted with clamping bolts and recessed in the timbers. The heads of these form mooring-posts for the caisson when it is berthed alongside, and heavy billian timber logs are bedded in the clay for it to rest upon when not water-borne.

A gauge is fitted to the dolphin on the up-stream side of the entrance showing the depth of water over the sill in feet.

Keel-Blocks.—These are of heavy native timber (billian and perpat) in four parts, weighing between 70 and 80 lbs. per cubic foot. They are not anchored to the floor of the dock in any way, and are placed 6 feet apart between centres.

There were only two accidents of a serious nature to the men employed during the construction of the dock, neither being fatal.

The dock was officially opened on the 31st May, 1912, by H.H. The Ranee Muda, when it was named the "Brooke" Dock.

The works described in this Paper were designed and carried out by the Author while holding the position of Commissioner of Public Works and Surveys to the Sarawak Government. He wishes to express his thanks in the first place to H.H. The Rajah of Sarawak, G.C.M.G., for permitting this Paper to be presented to The Institution; to all the members of his staff for valuable assistance; to Mr. H. W. Clarke, Assoc. M. Inst. C.E., for valuable assistance and advice in designing the dock and caisson-gate; and to Mr. D. Macdonald, M. Inst. C.E.

The Paper is accompanied by 10 sheets of drawings, from which the Figures forming Plate 5 have been selected.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

The High-Level Tank.

Cost of Reinforced-Concrete Tank.

	$
Materials—	
Cement	1,601·87
Stone	320·00
Expanded metal	462·42
Iron and steel	777·78
Timber	287·19
Other materials	697·45
Total	4,146·71
Labour	5,512·57
Supervision	624·31
Total	10,283·59
Total cubic feet of reinforced concrete	7,477
Average cost per cubic foot $\frac{7,477}{10,284}$	= say, 1·375

The dollar used = 2*s.* 4*d.*

Estimated Cost of Cast-Iron Tank.

	£	*s.*	*d.*
70,000 gallons cast-iron tank f.o.b. Liverpool	784	0	0
Foundations (actual)	253	0	0
Shipment to Sarawak, including transhipment at Singapore, say, 85 tons at £2 5*s.* per ton.	191	5	0
Transporting ½ mile from wharf to site, say, 75½ tons at 2*s.* per ton	7	11	0
Erecting with native labour, say, £2 per ton	151	0	0
Painting one coat after erection and caulking, including pipe-connections, say	12	0	0
Water-gauge, say	10	0	0
Insurance against loss and breakage from Singapore, say	16	0	0
Total	1,424	16	0

Or in dollars	$12,210·53
Actual cost of reinforced-concrete tank, as erected in Kuching	$10,283·59
Difference in favour of reinforced-concrete tank	$1,926·94

APPENDIX II.

THE BROOKE DRY DOCK.

Summary of Cost.

The dollar used = 2*s.* 4*d.*

	$
Materials—	
Cement	21,720·67
Stone	8,874·95
Sand	1,110·35
Fuel (coal)	2,951·40
Timber	1,143·47
Other materials	1,844·51
Sundries	4,948·36
Total	42,593·81
Labour	48,443·38
Total	91,037·19

The total quantity of cement used in the work was 5,430 barrels.

NOTE.—Up to and including section 27 the actual quantity of concrete as it came from the mixer was carefully noted, and if 13·24 per cent. is allowed for shrinkage when rammed and consolidated in situ, this gives about 20 per cent. as the volume occupied by displacement stones, which, in the Author's opinion, is approximately correct.

The total calculated quantity of concrete used in constructing this dock was 5,795 cubic yards.

(*Paper No. 4076.*)

"The Corrosion of Mild Steel used for Locomotive Boiler-Tubes."

By Eric Earnshaw Howell, M.A., Assoc. M. Inst. C.E.

The corrosion of steel being a subject which is at present occupying much attention, it is hoped that the following account of tests made with mild steel plates suitable for and taken from locomotive boiler-tubes may be of interest.

The test-pieces employed, 2·5 inches by 1·5 inch by 0·1 inch thick, were polished, and were then immersed for various periods of time in acidulated and other waters, as referred to below, the corrosion being measured by the loss of weight. Tests were made with water containing 0·5 per cent. and 0·05 per cent. sulphuric acid (even the lower percentage of sulphuric acid represents an exceptionally acid water), and in 1, 2, and 5 per cent. of magnesium chloride. The principal series of tests were, however, made with boiler waters kindly supplied by the chief mechanical engineers of several railways, obtained, with one exception, by blowing off from the boilers after a period of use, so as to be in the most concentrated form. Two samples from the main were also supplied. The tests were taken in both cold and boiling water, and also in boiling water with a current of air bubbling through it. Distilled water was added as required to make up for any loss by boiling. As a standard of comparison of corrosion, tests were made with distilled water in every case.

Before commencing the tests on the boiler waters, it was desired to test various steels in order to discover the corrosive effects upon them by 0·5 per cent. and 0·05 per cent. solution of sulphuric acid. Four steels of similar analysis were taken and marked "A," "B," "E," and "F." The tests were carried out at room temperature (about 60° F.) during a period of 31 days, after which the test-pieces were cleaned and weighed, with the results contained in Table I.

TABLE I.—CORROSION IN WATER ACIDULATED WITH SULPHURIC ACID.

	Loss in 0·5 Per Cent. Solution in Grammes.	Relative Corrosion.	Loss in 0·05 Per Cent. Solution in Grammes.	Relative Corrosion.
A	0·336	96·4	0·0718	98·6
B	0·349	100·0	0·0728	100·0
E	0·358	102·6	0·0743	103·5
F	0·367	105·0	0·0746	103·9

For the purpose of relative corrosion or loss of weight the steel marked "B" was taken as 100 in each case, because it is the steel chiefly employed by the Author's firm for locomotive boiler-tubes, and it was used for all the tests made with solutions of magnesium chloride and with the waters received from the various railways. It is interesting to note that whereas steel "B" lost some of its weight by pitting, steel "A" corroded evenly all over its surface; it is probable, therefore, that steel "A" in actual service will last longer than steel "B," and it is now being tested in actual service in order to ascertain whether the laboratory tests are confirmed. Steels "E" and "F" behaved similarly to steel "B."

TESTS WITH MAGNESIUM CHLORIDE SOLUTIONS.

All the test-pieces were cut from the same finished tube made from steel "B," and duplicate samples were tried in each percentage of magnesium chloride and in distilled water. The tests referred to in Table II were carried out at room temperature, and lasted 56 days.

TABLE II.

Solution.	Loss per Square Inch in Grammes.	Relative Corrosion.
Distilled water	0·041	100
1 per cent. $MgCl_2 6H_2O$	0·040	98
2 ,, ,, ...	0·0385	94
5 ,, ,, ...	0·0375	91

It appears that the presence of magnesium chloride up to 5 per cent. slightly reduces the corrosive properties of waters when the tests are made at room temperature. This is in accordance with the results of Heyn and Bauer, who used a commercial wrought iron in their experiments, but is in disagreement with the results of Friend and Brown, who used specially pure iron. Friend's tests, however, lasted only 14 days.

The results given in Table III were obtained with solution boiling for 8 hours per diem during a period of 56 days.

The test pieces were cut from steel "B."

TABLE III.

Solution.	Loss per Square Inch in Grammes.	Relative Corrosion.
Distilled water	0·0223	100
1 per cent. $MgCl_2$ $6H_2O$	0·0242	109
2 ,, ,, ...	0·0267	120
5 ,, ,, ...	0·0308	138

As the solutions were only boiling for about 8 hours per diem, the probability is that had the temperature remained the same continuously there would have been a greater corrosion.

It will be observed that in the cold magnesium chloride test there was less corrosion with increasing concentration of magnesium chloride, but the hot test shows the contrary result. This is probably due to the fact that the magnesium chloride decomposes in hot but not in cold solutions, thus setting free a certain amount of free hydrochloric acid which attacks the steel. All the test-pieces were uniformly corroded and were not pitted.

In these tests the water was boiling under atmospheric pressure: had it been boiling under boiler pressure, and therefore at higher temperature, there is every probability that the corrosion would have been still more marked, because the magnesium chloride would have been more completely decomposed at the higher temperature, setting free a greater amount of hydrochloric acid.

TESTS MADE WITH CONCENTRATED BOILER WATER SUPPLIED BY VARIOUS RAILWAY COMPANIES.

First Series of Tests (*Cold Water*).—The test-pieces were all cut from one long tube of steel B. The tests were carried out at room temperature for a period of 55 days, and the results are given in Table IV, where the various waters are placed in the order of their corrosive properties, the most corrosive being placed last. Taking distilled water as 100, the relative corrosion of the other waters is given in the third column.

TABLE IV.

Water.	Loss per Square Inch in Grammes.	Relative Corrosion taking Distilled Water as 100.
North British Railway, Carlisle	0·0113	31
Great Central Railway, Mexborough	0·0244	66
London and North-Western Railway, Crewe	0·0252	68
Great Western Railway, South Wales	0·0312	84
Lancashire and Yorkshire Railway, Bolton	0·0328	89
Midland Railway, Grimesthorpe	0·0342	92
Distilled water	0·0369	100
Lancashire and Yorkshire Railway, Newton Heath	0·0369	100
,, ,, ,, Accrington	0·0464	124
,, ,, ,, Low Moor	0·0470	127
,, ,, ,, Wakefield	0·0505	136
North-Eastern Railway (Drypool), Hull	0·0507	137
Great Western Railway, Birmingham	0·0512	139

Second Series of Tests (*Cold Water*).—These tests were made at room temperature for a period of 60 days with boiler waters received after the first series of tests were completed (see Table V).

Third Series of Tests (*Hot Water*).—These tests lasted 42 days, and were made in the same manner as the cold tests; but the water was kept boiling for 8 hours each day. Loss of water due to evaporation was covered by adding distilled water. The results are given in Table VI.

TABLE V.

Water.	Loss per Square Inch in Grammes.	Relative Corrosion taking Distilled Water as 100.
North British Railway, Carlisle	0·014	39
London and North-Western Railway, Crewe	0·014	39
Great Central Railway, Mexborough	0·022	61
Midland Railway, Canklow	0·024	67
Lancashire and Yorkshire Railway, Bolton	0·024	67
Midland Railway, Grimesthorpe	0·028	78
London, Brighton and South Coast Railway (Main), Three Bridges	0·031	86
Great Western Railway, South Wales	0·035	97
Distilled water	0·036	100
London, Brighton and South Coast Railway (Main), Eastbourne	0·036	100
Lancashire and Yorkshire Railway, Newton Heath	0·036	100
North-Eastern Railway (Drypool), Hull	0·038	106
Lancashire and Yorkshire Railway, Accrington	0·044	122
,, ,, ,, Wakefield	0·044	122
,, ,, ,, Low Moor	0·045	125
Great Western Railway, Birmingham	0·051	142
London, Brighton and South Coast Railway (Boiler), Eastbourne	0·061	170
0·05 per cent. sulphuric acid	0·071	197

The result given by the water from the North British railway was unexpected, and was probably due to a piece of mill-scale rolled into the tube having become detached. It will be observed in the next Table that this water gives similar results to those of the cold-water tests.

Fourth Series of Tests (Hot Water).—These tests were carried out in a similar manner to those referred to above for a period of 42 days, and the results are given in Table VII.

It will be observed that the Brighton railway, Three Bridges, water is more corrosive than Eastbourne boiler water. It is stated that Three Bridges water gives the best results on the Brighton railway. The reason Eastbourne boiler water corrodes less is that, having been in the boiler, it has had all the oxygen driven out of solution, whereas the Three Bridges water, direct from the main, will contain its full amount of oxygen. It will be noticed that Eastbourne water from the main is more corrosive than the same water from the boiler, whereas in the cold-water test (Table V) the positions of

TABLE VI.

Water.	Loss per Square Inch in Grammes.	Relative Corrosion taking Distilled Water as 100.
Great Western Railway, Birmingham	0·0208	56
Lancashire and Yorkshire Railway, Low Moor	0·0224	60
,, ,, ,, Bolton	0·0251	67
,, ,, ,, Newton Heath	0·0269	72
,, ,, ,, Accrington	0·0323	87
,, ,, ,, Wakefield	0·0348	94
Distilled water	0·0372	100
North-Eastern Railway (Drypool), Hull	0·0376	101
Great Western Railway, South Wales	0·0378	102
London and North-Western Railway, Crewe	0·0396	106
North British Railway, Carlisle	0·0444	119
Great Central Railway, Mexborough	0·0546	146
Midland Railway, Grimesthorpe	0·0565	152

these two waters are reversed. The reason appears to be that, although the boiler water contained a concentration of corrosive salts as compared with that from the main, it would absorb during the progress of the cold test atmospheric oxygen to the same extent as the main water, which, combined with its increased amount of corrosive salts, would cause the boiler water to corrode more than the water from the main in the case of the cold tests.

In the case of the hot tests, the boiler water starting with little dissolved oxygen would have little or no opportunity of dissolving any, as the tests were carried out in the heated state; but the water from the main was fully charged with dissolved oxygen, and only a portion would escape on heating: the remaining oxygen attacks the steel, and thus the main water is more corrosive in hot solution than is the boiler water.

The North British water gives a better result than in the previous hot-water test. This result was expected and was confirmed by a duplicate test. It will be noted that the Midland and Great Central railway waters, which take a good position in the cold-water test, Table V, fall to the bottom of the list in the hot-water tests. The other waters maintain their position.

TABLE VII.

Water.	Loss per Square Inch in Grammes.	Relative Corrosion taking Distilled Water as 100.	Appearance of Test-Pieces.
North British Railway, Carlisle	0·013	43	Bright in parts, very little corroded.
Great Western Railway, Birmingham	0·019	63	Dark brown to black, very little corroded.
London and North Western Railway, Crewe. .	0·021	70	Bright in part, dark brown, little corroded.
Lancashire and Yorkshire Railway, Newton Heath	0·022	73	Dark brown, little corroded.
Lancashire and Yorkshire Railway, Bolton. . .	0·022	73	Black, little corroded.
Lancashire and Yorkshire Railway, Low Moor. .	0·025	83	Bright in parts, little corroded.
North Eastern Railway (Drypool), Hull. . .	0·028	93	Brown, little corroded.
Great Western Railway, South Wales. . . .	0·029	96	Bright in parts, slightly pitted.
Lancashire and Yorkshire Railway, Wakefield . .	0·029	96	,, ,, ,,
Lancashire and Yorkshire Railway, Accrington .	0·029	96	,, ,, ,,
Distilled Water . . .	0·03	100	Dark brown to black, uniformly corroded.
London, Brighton and South Coast Railway (Boiler), Eastbourne .	0·031	103	,, ,, ,,
London, Brighton and South Coast Railway (Main), Three Bridges .	0·036	120	Bright all over, uniformly corroded.
Great Central Railway, Mexborough	0·045	150	,, ,, ,,
London, Brighton and South Coast Railway (Main), Eastbourne. .	0·047	156	,, ,, ,,
Midland Railway, Grimesthorpe	0·048	160	,, ,, ,,
Midland Railway, Canklow	0·049	163	,, ,, ,,

Fifth Series of Tests (Hot Water with Added Oxygen).—These tests were carried out during a period of 42 days in a similar manner to the previous hot-water tests, but during the whole time a stream of air was bubbling through the water. These tests were carried out in order to ascertain the effect of air dissolved in the feed-water of a locomotive boiler as is usual in everyday practice, especially where the water is picked up at a high speed from a trough. The results are given in Table VIII.

TABLE VIII.

Water.	Loss per Square Inch in Grammes.	Relative Corrosion taking Distilled Water as 100.	Appearance of Test-Pieces.	Multiplication Factor of Increased Corrosion by Weight as compared with Table 7.
North British Railway, Carlisle	0·089	70	Bright in parts, very little corroded	6·8 X
London and North Western Railway, Crewe . . .	0·090	71	Bright in parts, somewhat pitted .	4·3 Z
Lancashire and Yorkshire Railway, Newton Heath.	0·104	82	Brown to black, bright parts, little corroded . . .	4·7 Z
Lancashire and Yorkshire Railway, Bolton . . .	0·105	83	Bright to black, uniformly corroded .	4·8 Z
Lancashire and Yorkshire Railway, Low Moor . .	0·110	87	Bright to brown, slightly pitted .	4·4 Z
North Eastern Railway (Drypool), Hull . . .	0·115	91	Bright to brown, slightly pitted .	4·1 Z
London, Brighton and South Coast Railway, Three Bridges	0·115	91	Bright all over, uniformly corroded .	3·2 Y
Lancashire and Yorkshire Railway, Wakefield . .	0·120	95	Bright to black, slightly pitted .	4·1 Z
Lancashire and Yorkshire Railway, Accrington. .	0·122	97	Bright in parts, slightly pitted .	4·2 Z
Great Western Railway, Birmingham	0·122	97	Brown to black, pitted	6·4 X
Distilled water	0·126	100	Brown to bright, very slightly and evenly pitted . .	4·2 Z
Great Central Railway, Mexborough	0·128	102	Bright all over, uniformly corroded .	2·8 Y
London, Brighton and South Coast Railway (Main), Eastbourne	0·128	102	Bright to brown, slightly pitted .	2·7 Y
Great Western Railway, South Wales	0·134	106	Bright to brown, very slightly pitted	4·6 Z
London, Brighton and South Coast Railway (Boiler), Eastbourne	0·142	113	Brown to black, very slightly pitted	4·6 Z
Midland Railway, Canklow	0·144	114	Bright all over, uniformly corroded .	2·9 Y
Midland Railway, Grimesthorpe.	0·144	114	Bright all over, uniformly corroded .	3·0 Y

The fifth column in this Table gives increased corrosion due to the free access of oxygen, thus the water from the North British railway, Carlisle, corrodes 6·8 times as rapidly when an excess of oxygen bubbles through it as when it contains only its normal amount of oxygen in solution as in the previous hot test (Table VII).

The corrosibility of the waters marked "X" is very much increased by access of oxygen, but waters marked " Y " are not so much altered, that is, only three times as much; waters marked " Z " hold an intermediate position.

The average increase of corrosion for all waters is 4·4 times the amount of corrosion with the normal amount of oxygen.

CONCLUSIONS.

It would appear that the first and most obvious conclusion to be drawn from the foregoing research is that some inexpensive method should be devised to eliminate the air from the feed-water before passing it into locomotive boilers.

If the feed-water contains dissolved oxygen it is not surprising if certain tubes or parts of them are corroded more rapidly than the remainder.

Steel which corrodes equally all over its surface and loses the same aggregate weight will last longer than a steel which corrodes by pitting, and the only satisfactory way of determining the practical effect is by testing the steels in actual practice, and in more than one boiler.

Steels of similar analysis may differ in corrosion results, and hence steel made in different works, to the same specification, may give different corrosion results. It would follow that it is not advisable to mix tubes of different manufacture in the same boiler.

(*Paper No. 4072.*)

" Dust-Explosions."

By JOHN DAVID MORGAN, Assoc. M. Inst. C.E.

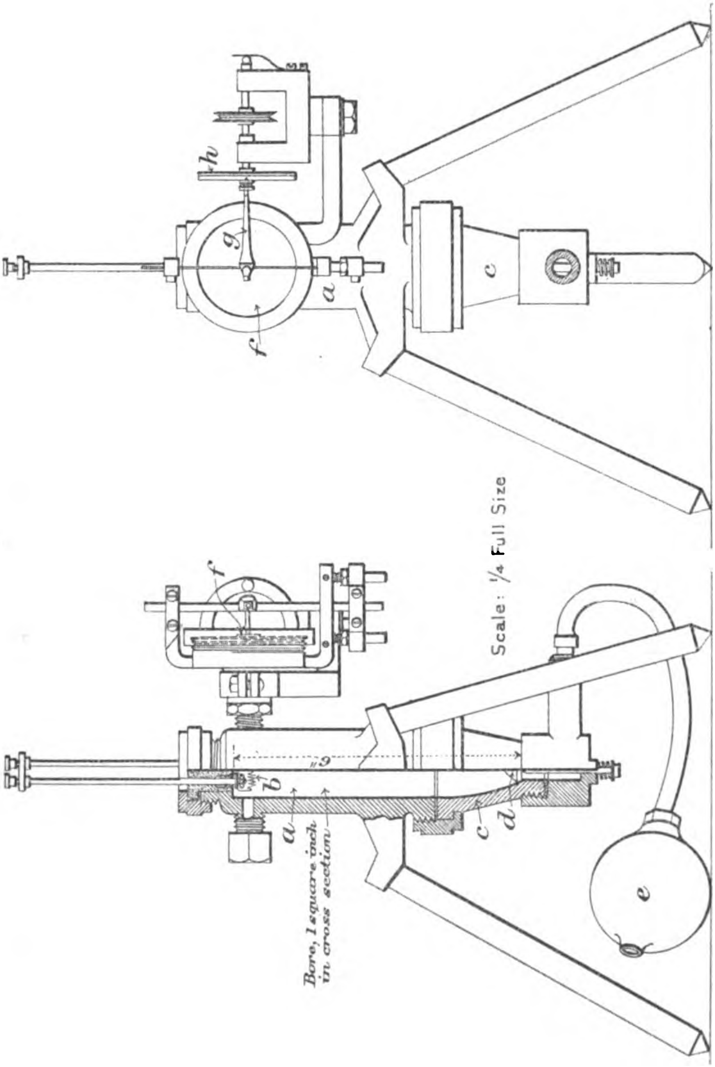
(*Abstract.*)

THE subject of dust-explosions is of interest in different ways both to engineers responsible for the safety of mills and mines, and to those employed on problems of power-generation. The present Paper describes some results of research carried out by the Author on the principal properties of explosible dust-clouds.

It is generally agreed that a mixture of dust and air may be regarded as a coarse gas-mixture. For investigating the explosiveness of dust-clouds uniformly distributed throughout a confined air-space, the apparatus shown in *Figs. 1* was designed. It consists of a cylindrical metal body *a*, provided at the upper end with an insulating plug carrying the terminals of a platinum igniting-coil *b*. At the lower end is a detachable cup *c*, fitted with a valve *d* and a rubber air-bulb *e*. A quantity of dust placed in the cup is raised in the form of a cloud by a puff of air injected from the bulb. When the upper part of the cloud reaches the coil *b* ignition occurs, and inflammation proceeds throughout the cloud. The internal volume of the chamber is 105 cubic centimetres. For indicating the pressures obtained a flexible disk-gauge was employed. A thin metal disk *f* is clamped rigidly around its edge, and at its centre is provided with a point which bears against either the back of a mirror employed to reflect a pencil of light from a lamp on to a scale, or a style *g* arranged to produce a graphic record on a smoked card revolved at a known rate by a holder *h*. Two examples of diagrams are shown at *Figs. 2*. Pressures are measured along radial lines, commencing at the outer circle, which is the line of original pressure. The inner concentric circle indicates the final pressure. The diagrams (*Figs. 5 to 8*) hereinafter discussed express the relationship between pressure and time in terms of rectangular co-ordinates, and are obtained from the automatically-recorded polar diagrams.

Using lycopodium, the first principal result observed was that a certain critical charge produced the maximum explosion-pressure, and an increase of charge beyond this amount was accompanied by diminution of the explosion-pressures. The curve in *Fig. 3* illus-

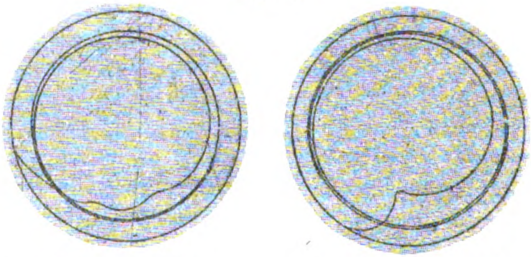
Figs. 1.


h
g
f
a
c
Scale: 1/4 Full Size
f
b
6"
a
Bore, 1 square inch in cross section
c
d
e

trates the relationship between the quantity of dust scattered uniformly through the explosive chamber of the apparatus and the pressures obtained. This curve should settle any doubt which might exist on the point under consideration. It has been asserted that excess of dust cannot have a diminishing effect upon the maximum pressures obtainable from the explosion of a given dust, on the assumption that part of the dust in the cloud completely combines with the available air, and the remainder of the dust is unaffected. But, as the curve shows, excess of dust has a damping effect upon an explosion, and in every variety of experiment of which the Author has any knowledge this fact was always observed.

It will be noticed that the fall of pressure on the right-hand side of the peak is very rapid as far as charges of 0·15 gramme. For greater charges the drop is more gradual. This result is true for the apparatus, but is not strictly true for experiments carried out under ideal conditions. Owing to the rapidity of combustion of the dust and the consequent rise of pressure in the apparatus sufficiently to cause the valve *d* to close against the air-pressure from the bulb *e* before the cloud formation was complete, it was not possible to project into the explosion-chamber the whole of the dust in a charge greater than about 0·15 or 0·2 gramme. Consequently the pressure connected with a given charge is that due to inflammation of only part of the charge. If the whole of the charge had been inflamed, a still less pressure than that recorded would have been obtained. These remarks apply only to the lower part of the curve. With the smaller charges, practically the whole of each charge was utilized.

Figs. 2.



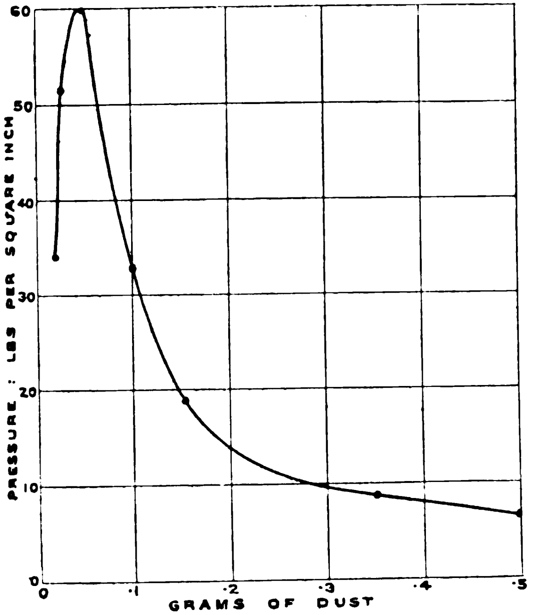
COAL DUST
(*with small admixture of Lycopodium dust*)

LYCOPODIUM DUST

It will be observed that the smallest charge which could be ignited was 0·02 gramme. Charges of this weight gave an average pressure of 34 lbs. per square inch. Smaller charges of 0·01 and

0·015 gramme were tried, but no ignition could be produced. Charges of 0·025 gramme gave an average pressure of 51·5 lbs. per square inch and of 0·05 gramme an average pressure of 60 lbs. per square inch. The same charges occasionally produced widely different pressures. Sometimes much lower pressures than the average were obtained, obviously due to imperfect formation of the dust-clouds. At other times much higher pressures were produced than those recorded, for example, 70 and 80 lbs. per square inch with charges of 0·05 gramme. These the Author is unable to explain, unless on the assumption that the clouds which resulted in the average explosion-pressures were not of exactly the same density throughout and the clouds which gave the abnormally high pressures more closely approached the condition of ideal uniformity, or the various clouds, though similar in the distribution of the particles, differed in their relative states of turbulence. The net pressures due to the explosion is obtained by deducting from the recorded pressures the amount 3·5 lbs., which is the initial pressure due to the air injected to form the cloud.

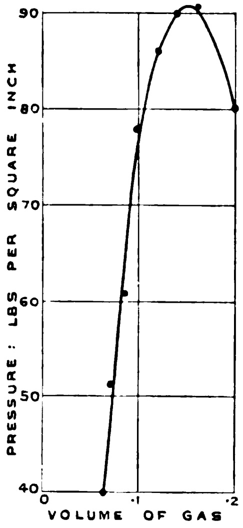
Fig. 3.



The earlier part of the curve (*Fig. 3*) is similar in general shape to those connecting the charges and pressures in gas explosions, as will be seen on reference to *Fig. 4.* The latter is based on a Table given by Dr. Dugald Clerk,[1] the abscissas representing the volume of gas in a unit volume of gas and air mixture.

Ignition, Inflammation and Combustion.—These terms are employed in the following sense: ignition is the inception of burning, inflammation is the propagation of burning through the mixture, and combustion is the whole process of burning. Ignition of a dust-cloud depends upon (*a*) the temperature, (*b*) the quantity of heat available, (*c*) the fineness of the dust particles, and (*d*) the density of the cloud. Inflammation depends upon the further condition of turbulence.

Fig. 4.



On the relationship between factors (*a*) and (*b*) there appears to be much need of research, especially in connection with electrical means of ignition. On the ignition temperatures of various inflammable dusts produced in industrial operations, Dr. Wheeler has recently published the results of experiments made at Eskmeals on behalf of the Home Office.[2] The Author's experience is that different dusts are distinguished more by the quantity of heat required to ignite them than the temperature of the igniting medium. For example, the small electric spark of a plug such as is used in petrol engines will not ignite a cloud of lycopodium dust, but a broad stream of sparks passing between specially arranged pole pieces substituted for the plug in the same apparatus will ignite the cloud. The same stream of sparks will not ignite a cloud of oil-cake dust, but a small glowing platinum coil will ignite the cloud. Further, the same coil will not ignite a cloud of some coal-dusts in such a manner as to cause inflammation or propagation of the flame throughout the cloud. Yet if a Bunsen flame be employed, propagation of the flame through the cloud is readily obtained.

Considerable misapprehension appears to exist as to the conditions necessary to inflame a combustible dust-cloud. A dust-cloud will not inflame if it is insufficiently dense, or if the igniting medium is unsuitable to produce inflammation or propagation of a flame through the cloud. Further, if the cloud is too dense inflammation is quickly stifled after ignition. Statements concerning the ignitibility of clouds by sparks require to be made with great reserve, as sparks may vary considerably in size, and it is difficult, if not impossible, to distinguish logically between a spark and an arc or flame. The arc which occurs at a switch might be regarded as a spark, and such a spark may easily be dangerous in the presence of a highly inflammable cloud. The arc produced at a knife switch when breaking an inductive circuit through which 25 amperes was passing was found to be capable of igniting a lycopodium cloud, though not a coal-dust cloud. Mr. L. C. McNair [1] obtained the following results in experiments on oil-cake dust: No ignition could be obtained by projecting a shower of sparks produced by rubbing a piece of steel on a revolving emery-wheel, inserting a lighted match, breaking a lighted incandescent lamp (16 candle-power carbon), inserting a lighted pipe or cigarette kept glowing by a rubber hand-pump, fusing a single No. 26 fuse-wire, $1\frac{5}{8}$ inch long, when raising the current gradually, or sparking between two flexible wire leads forming a circuit with an incandescent lamp (16 candle-power carbon). Ignition was obtained, however, by an ordinary Bunsen flame, an ordinary gas-jet flame, a match ignited by a heated wire in a cloud, burning magnesium ribbon, a spark formed by breaking an electromagnet circuit, and a fuse-wire blown by an excessive current.

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[1] Dugald Clerk, "The Gas Engine." 6th ed., p. 100.

[2] Home Office Report on inflammability and capacity for transmitting explosions of carbonaceous dusts, by R. V. Wheeler, March, 1913.

As already stated, much work requires to be done on the subject of ignition and inflammation, not only for the purpose of pointing out what is dangerous, and thereby safeguarding life and property, but also for indicating what is safe, and thereby avoiding obstruction to the proper use of electrical apparatus where otherwise it might be considered dangerous.

Figs. 5 to *8* show indicator-diagrams obtained from the explosion of various dusts in the apparatus illustrated in *Figs. 1*. In each diagram the abscissas denote time and the ordinates pressure. *Fig. 5* shows curves obtained from the explosion of four different charges of lycopodium dust. The smallest charge gave the highest maximum pressure and the largest charge gave the lowest maximum pressure. Intermediate values were obtained with intermediate charges. The most rapid inflammation was obtained with the smaller charges, whilst with the largest charge inflammation was comparatively slow. Further, with the smallest charge, combustion was complete when the maximum pressure was attained as the cooling portion of the curve is practically a true hyperbola. The cooling is slower as the charges increase, denoting that combustion continues after the maximum pressure has been attained. This effect is very marked in the curve of the largest charge,

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[1] Report of H.M. Inspectors of Factories on the explosion at Messrs. J. Bibby and Sons' factory, Liverpool, January, 1912.

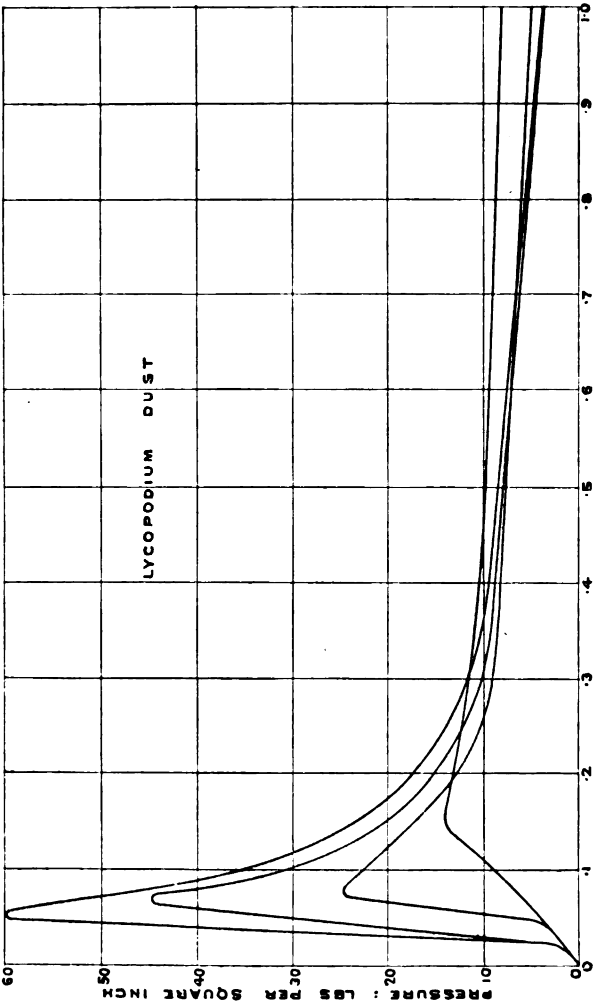

Fig. 5.

Fig. 6 shows characteristic curves obtained with various dusts:—

No. of Curve.	Material.
1	Wood dust (railway-carriage works).
2	Sugar.
3	Starch.
4	Flour.
5	Sulphur (milk of).

It will be observed that the curves are all of regular configuration, the inflammation being relatively rapid in each case and combustion practically complete in the region of maximum pressure, except in the case of flour, where the cooling curve is markedly flat. These curves are not intended to show the maximum pressures obtainable with the dusts employed, but the general character of the explosions. The amounts of the charges were guessed, although they were known from experience to be approximately of the amounts required for producing maximum pressures. With larger charges the same characteristics as those indicated in *Fig. 5* were found.

Fig. 7 shows a number of typical curves obtained from the explosion of oil-cake dust. These illustrate the effects obtained with four charges of different sizes, and, whilst in relation to each other, they conform to the general rule that increase of charge diminishes the maximum pressure obtainable, yet, as compared with the curves shown in *Figs. 5* and *6*, they exhibit certain peculiarities. In the first place inflammation is much slower, and secondly it does not proceed uniformly throughout the cloud, except, perhaps, in the case of the smallest charge (No. 1).

Similar peculiarities were observed in the combustion of coal-dust (see *Fig. 8*). With the platinum coil used it was found impossible to ignite the dust-clouds of certain coals in such a manner as to produce propagation of flame throughout the cloud.[1] A Bunsen flame ignited a cloud readily, but the coil produced only local ignition, and the flame from the ignited portions of dust did not spread throughout the cloud. It was noticed that with a large flame-surface the difficulty of propagation disappeared, and in consequence a little lycopodium dust was mixed with the coal-dust to produce, on ignition, the necessary flame for igniting the coal. The curves in *Fig. 8* were produced by coal-dust explosions obtained in this manner. To what extent the maximum pressures are affected by the lycopodium is not known, but, having regard to the curves for lycopodium dust only (*Fig. 5*), it is believed that the presence of lycopodium in the explosion does not affect the other characteristics of the coal-dust curves. With the smallest charge of coal-dust a comparatively rapid and uniform rise of pressure is obtained. Larger charges are, however, accompanied by that

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[1] Coal-dusts vary greatly in their combustibility. The samples used were produced from domestic coal obtained in Birmingham, but the Author does not know from what colliery it originated. Professor Cadman has since supplied samples which explode much more readily than those used in the experiments described.

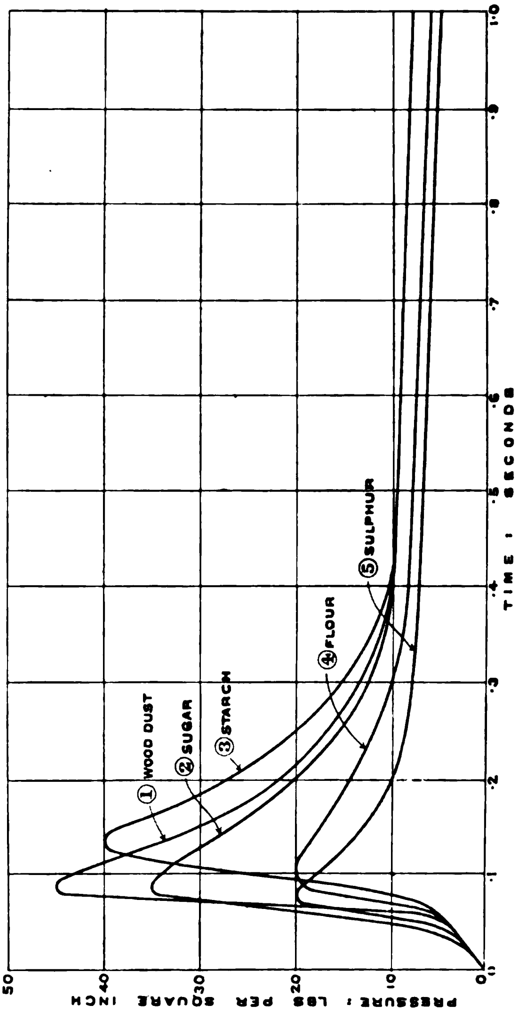

Fig. 6.

irregular inflammation which in a less marked degree is found in the curves on oil-cake dust (*Fig. 7*). In regard to this irregularity, it may be urged that the material undergoes a process of disintegration or distillation during combustion, and that the "humps" in the curves are due to the successive inflammation of volatile or more easily combustible constituents liberated by the heat produced in the earlier stages of combustion. The Author believes, however, that the irregularities are more probably due to the heterogeneous character of the dust, some parts being more readily ignitible than others. The first effect of ignition is to inflame a part of the cloud, and the heat thus produced ignites and inflames the less inflammable constituents.

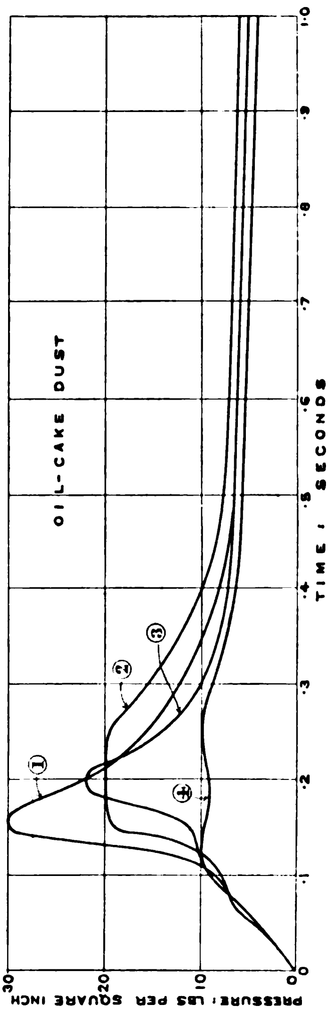

Fig. 7.

The principal conclusion to be drawn from *Figs. 5* to *8* is that different materials behave differently on ignition. Using the same igniting device, some dusts inflame rapidly and uniformly, others inflame less rapidly and irregularly, whilst others will not inflame at all, ignition being confined to the parts in contact with the igniting device. The latter materials require to be ignited by an extended heating-surface before inflammation (or propagation of the flame throughout the cloud) can be produced. Dr. Wheeler, in his Report[1] issued subsequently to the completion of the above experiments, divides inflammable dusts into three classes, namely, (1) Dusts which ignite and propagate flame readily, such as starch, sugar, flour;

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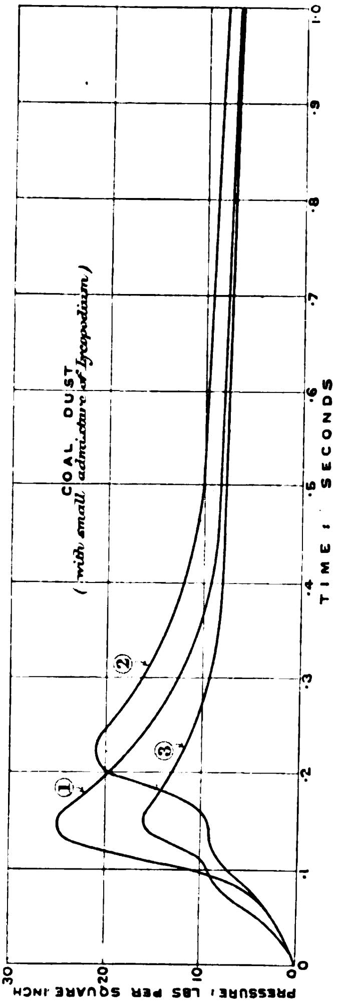
[1] See p. 338.

(2) Dusts which are readily ignited, but which require a source of heat of large size and high temperature for propagation of the flame, such as saw-dust and oil-cake; and (3) Dusts which do not appear to be capable of propagating flame under any condition likely to obtain in a factory, such as charcoal and foundry blacking. In this latter class some coal-dust must also be placed. The above classification substantially confirms the Author's conclusion, but even this must apparently be accepted with some reserve, for among the most explosive of the common dusts used in the experiments here recorded was wood dust gathered from the beams of a railway-carriage works (see *Fig. 6*), and wood dust in Dr. Wheeler's classification is found in the second class. Obviously, therefore, wood dusts vary in inflammability. It is believed that the apparatus illustrated in *Figs. 1* and the curves produced afford convenient means for easily determining the relative explosibility of different dusts.

Fig. 8.



As regards ignition temperatures, the following figures taken from the large number in Dr. Wheeler's report may be quoted:

	°C.
Wood dust	970
Starch	1,035
Sugar	805
Flour	1,060
Oil-cake	945
Coal-dust .	1,000 to 1,100

Explosions in Dusty Culverts.—In this connection the primary questions appear to be (1) What condition of the air is necessary for the raising of a cloud of dust? and (2) What condition of the suspended dust is necessary for indefinite propagation of the flame?

Experience indicates that:—Dust clouds can be raised by (*a*) a simple current of air, (*b*) longitudinal vibration of the air, and (*c*) sudden change in the motion of a simple current such as rapid reversal, whilst to obtain indefinite propagation of the flame the dust must not be in excess of that amount which can completely combine with the available air.

When a current of air alone is employed for raising a cloud of dust, the surface dust is caught up and swirled into eddies which travel along with the current. Comparatively thin clouds are produced in this way, and unless a strong current is used the dust is not lifted far above the surface of the stationary dust lying along the base of the culvert. When a strong wave-motion is sent along the culvert a much more energetic disturbance of the dust occurs, the dust being raised for a considerable distance from the base of the culvert in a cloud which is comparatively dense at the antinodal points and diminishes in density towards the nodal points of the wave-motion. If in addition to the wave-motion a current of air is passed along the culvert, the dust raised by the wave-motion is carried along by the current, with the result that a comparatively dense and uniform cloud is produced throughout the entire length and section of the culvert. Using lycopodium in a glass tube, a small blast of air introduced at one end of the tube produced only a slight cloud, but when in addition to the same blast a wave-motion obtained by the sounding of a pneumatic motor-horn at the end of the tube was introduced, a dense cloud was raised which almost completely filled the tube. From

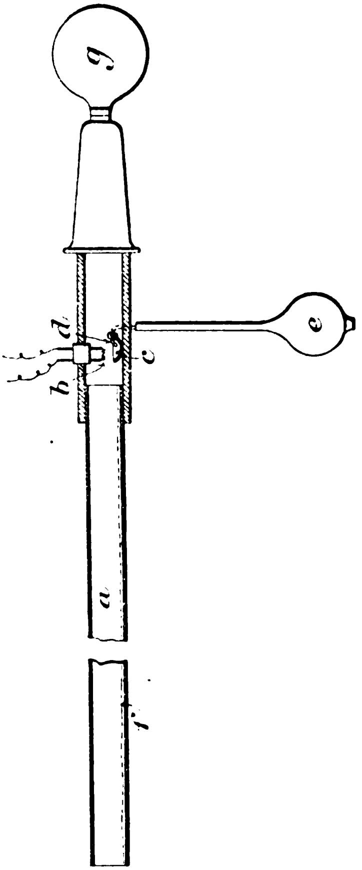


Fig. 9.

experiments with vibrations and impulses it is evident that sudden changes in the state of motion of the air are more serious agencies in the production of dust-clouds than currents having uniform motion.

To examine the transmission of flame under the two conditions of simple translation of air and translation combined with vibration, the apparatus shown in *Fig. 9* was used. A glass tube *a*, about 10 feet in length and 2¼ inches in diameter, was fitted at one end with a chamber containing a platinum ignition coil *b*, a concave dish *c* for the charge, and a glass jet tube *d* with air bulb *e* for blowing the charge across the coil. Lycopodium dust was strewn along the tube as indicated by *f*, and at one end of the tube was fixed a dummy motor-horn *g*, i.e., a horn without a reed. The sole purpose of the horn was to make the condition of the experiment similar to that in which a proper horn of identically the same proportions was used; the puff from the horn was negligible in its effect upon the dust. Firing of the charge (simultaneously with compression of the dummy horn bulb) produced a rush of air along the tube, and the dust thus raised fed the flame, which travelled with great velocity throughout the entire length of the tube. The original condition of the apparatus was then restored, and instead of the dummy horn a proper horn was used. Concurrently with the sounding of the horn, the charge was fired, and with few exceptions the flame could not be made to travel more than a foot or two along the tube, and in the majority of cases the distance travelled was less than a foot. Dense smoke was produced, and the flame was obviously extinguished by excess of dust. It follows, therefore, that excess of dust diminishes the extent to which flame can be propagated along a dusty channel, whilst comparatively thin clouds enable the flame to travel to a much greater distance, if not to an indefinite distance, provided the cloud raised is sufficiently dense to be ignitible.

The original Paper[1] also describes devices for preventing dust-explosions which have been successfully applied in mills, and discusses various proposals for rendering dust innocuous in mines.

In conclusion, the Author gratefully acknowledges his indebtedness to Mr. Edward C. R. Marks, Assoc. M. Inst. C.E., for generously placing the Marks and Clerk Laboratory in Birmingham at his service; and also to Mrs. J. D. Morgan, B.Sc., for her cooperation throughout the whole of the experimental work.

The Paper is accompanied by seventeen drawings, from which the Figures in the text have been selected.

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[1] In the Library of The Institution.

(*Paper No. 4065.*)

"Errors in Height-Scales of Barometers."

By ROLLO APPLEYARD, M. Inst. C.E.

IN view of the increasing use of aneroid and other barometers for survey work and for aeronautical purposes, it is important to consider the limits of accuracy with which measurements of height can be made with barometers. Errors due to mechanical hysteresis of the metal in aneroid barometers and those due to thermal inequalities have already received the attention of investigators.

The merits of the aneroid barometer as a field instrument for engineers have been discussed by Major B. R. Branfill.[1] His notes are the result of observations made during several years whilst he was conducting the Madras Party of the Great Trigonometrical Survey of India, and they are essentially of a practical character. In particular he shows the importance of diurnal variations, and he makes some useful remarks in regard to methods of recording observations, and the degree of accuracy to be attained in height measurements. Instrument-errors are carefully examined by Dr. C. Chree, F.R.S.,[2] who deals with the lag or elastic effect, observed respectively with ascending and descending readings, and also with secular changes and the influence of temperature on the indications of aneroid barometers. In neither of these Papers, however, are the errors in height-scales discussed. It may be remarked that estimates of height deduced from barometric readings may be vitiated by local storms. In survey work, errors arising from storms can be eliminated by taking additional pairs of barometric readings; but in aeronautics such a check cannot, in general, be applied. The "Kew" test, applied to aneroids, is only for the instruments considered as barometers; it does not include a check upon their height-scales.

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[1] "Notes on the Aneroid Barometer for the use of travellers and others in determining the relative heights of places in Southern India, with tables and a list of trigonometrical heights in and about the Province of Mysore." Bangalore, Mysore Government Press, 1871.

[2] "Experiments on Aneroid Barometers at Kew Observatory, and their Discussion." Phil. Trans. Royal Society, Series A, 1898, vol. 191, pp. 441-499.

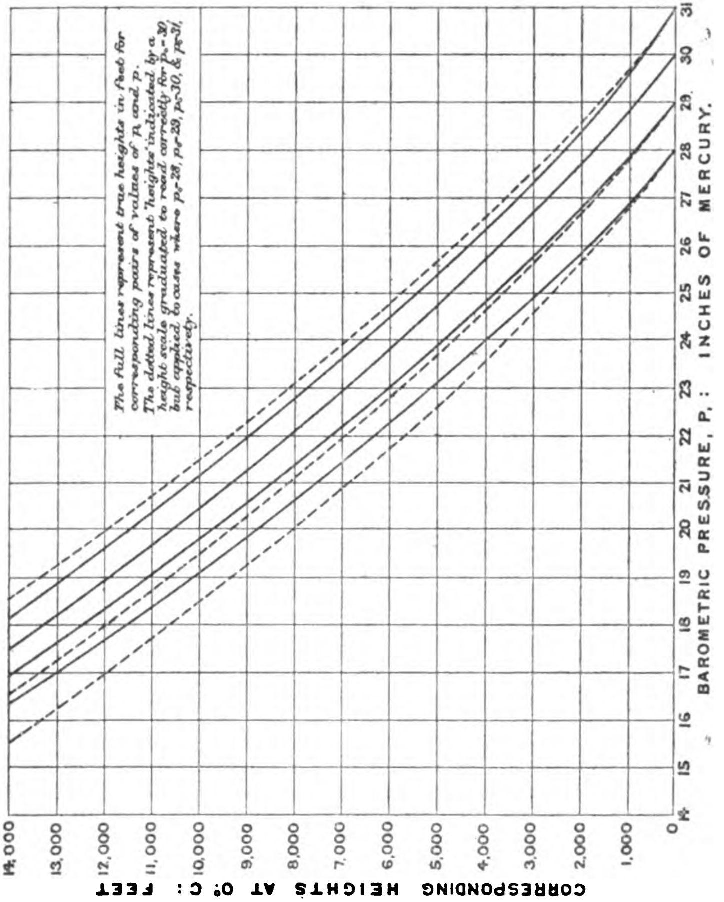
In the present Paper, therefore, it is proposed to determine the magnitude of the error likely to be introduced if the height is determined from the ordinary scale of heights attached to a barometer, instead of being calculated in each instance from the barometric readings observed at the lower and the higher stations respectively.

Height-Scale Inherent Errors.—It is shown in the Appendix that if p_0 is the barometric pressure at datum level, and p_1 the pressure at F feet above datum level, and that if it is assumed that there is an average temperature of 0° C. throughout that vertical distance, then, from equation (1)

$$F = 60{,}355 \times \log_{10} \frac{p_0}{p_1}.$$

Let the pressures be expressed in inches of mercury, and let p_0 be given the successive values 28, 29, 30, 31. A Table (Table I of the Appendix) can then be prepared to represent heights F corresponding with these values of p_0, for values of p_1 throughout any required range of heights. If some definite value of p_0 is now selected, a corresponding "height-scale" can be constructed which shall read directly and accurately in feet whenever the barometer at datum level happens to be at that selected value p^1_0, say 30 inches. When the barometric pressure at datum-level is other than p^1_0, the zero of the height-scale can be brought into coincidence with the new value of p_0, on the barometric scale of pressures, and the height-scale will indicate heights, subject to a correction, for which an expression has to be found (equation (2) in Appendix). The magnitude of the correction is represented graphically in *Fig. 1*, which is drawn from the values of heights and pressures given in Table I. In that curve the firm lines correspond with true heights, such as would be read upon a true scale upon a perfect barometer, for the four cases where p_0 is selected to be 28, 29, 30, 31 respectively. When determining the divisions for his height-scale, the instrument-maker has, in general, to select a single definite value for p_0, and for the present calculation it may now be assumed that he decided upon $p_0 = 30$. The effect of using such a scale for other values of p_0 is represented in *Fig. 1.* It is equivalent to sliding the firm line corresponding with $p = 30$ into successive positions, so that each point along it moves horizontally, and so that the lower extremity of it stops successively at 28, 29, 30, and 31, as indicated by the dotted lines. The height-scale errors are thus self-evident from the Figure, and they are considerable. The observer who uses the height-scale, instead of calculating his heights from the two barometric readings, in effect reads from the dotted lines instead of from the firm lines of the curves. For example, when $p_0 = 31$, a height of 9,000 feet is seen to correspond with 21·991 inches on the firm line. But the observer using the height-scale graduated on the 30 basis, and shifted along to the $p_0 = 31$ mark, would read this pressure not on the firm line but on the dotted line, and he would declare the height to be 9,340 feet instead of 9,000 feet. Thermal and hysteresis errors are of an

Fig. 1.



elusive character. The height-scale error, however, is definite, and by the means here described it can always be calculated and then eliminated or avoided.

Height-Scale Instrument Errors.—The general nature and the magnitude of the inherent errors of determinations of altitude, when a single height-scale graduated to a fixed selected basis is used in the manner above discussed, are indicated in the curves in *Fig. 1*, assuming the height-scale to be engraved accurately in accordance with the relationships of pressures and heights derived from calculations upon such a selected basis. In actual barometers provided with height-scales, however, the engraving may not precisely represent those relationships. Further errors are consequently introduced, which will here be referred to as "height-scale instrument errors."

Equations (1) and (2), in Appendix, and Table I, enable a rapid check to be applied to determine instrument errors of height-scales of existing barometers. For this purpose, the zero of the height-scale should be set to a definite mark, say 30, of the barometric scale, and keeping it at this position, the barometric readings coincident with, say, 1,000, 2,000, 3,000 . . . . feet on the height-scale should be written down, as in Table II. The true barometric readings corresponding to those heights for the selected zero setting can be added from Table I. The process can if necessary be repeated, for other zero settings such as 28, 29, or 31. In Table II, which is derived from readings of an actual instrument, this additional check is shown for a setting of 31. From inspection of the Table, it is manifest that if the height-scale of this particular instrument was originally based upon 30 by the instrument-maker, the divisions were imperfectly spaced. For this instrument the graduations corresponding to the 31 mark are rather better than the 30-mark graduations near 1,000 feet, but at 9,000 feet they are less accurate than those of the 30 mark. For example, for the 30 mark the difference at 1,000 feet is $28{\cdot}88 - 28{\cdot}67 = 0{\cdot}21$. Hence the height-scale instrument error, from equation (2), is there approximately $\delta F = -26{,}215 \frac{0{\cdot}21}{30} = -183$ feet. For the 31 mark the difference at 1,000 feet is $29{\cdot}84 - 29{\cdot}88 = -0{\cdot}04$, and, approximately, $\delta F = -26{,}215 \frac{-0{\cdot}04}{31} = 34$ feet. From the reversal of the sign of the height-scale instrument error, it follows that at or near 1,000 feet the basis of the scale for this particular instrument to give accurate results at that part of the height-scale must be between 30 and 31. By a similar process the height-scale instrument errors at 9,000 feet are seen to be, for a 30-mark setting, 177 feet, and for a 31-mark setting 241 feet, approximately. The height-scale instrument errors here determined have to be added to, or subtracted from, the inherent errors arising from the use of a fixed basis in making the height-scales.

It would appear that instrument makers could obtain better results if more care were exercised in engraving the scales. Until correctness in this work is secured, expenditure upon verniers and reading-lenses is wasteful and misleading. It would be a step in the right direction if there were denoted upon each instrument the basis upon which its height-scale is calculated. For accurate work engineers will see the wisdom of abandoning height-scales and using either equation (1), or a sheaf of curves similar to the firm lines in *Fig. 1.*

It is of course to be understood that equation (2) (Appendix) is strictly applicable only when δp is extremely small; nevertheless equation (2) is useful in obtaining a rough idea of the magnitude of instrument errors, as above. If great refinement is required in calculating instrument errors, equation (1) should be applied to each of the readings corresponding to selected pairs of pressures.

The Paper is accompanied by a diagram, from which *Fig. 1* has been prepared; also by the following Appendix.

[APPENDIX.

APPENDIX.

To find an expression for the height h, determined by two barometric readings p_0 and p_1, at the lower and higher levels respectively, at mean temperature t° C., and another expression to represent the error in the height measurement, assuming a small error in the "height-scale": consider a small vertical cylinder of the atmosphere, of 1 square centimetre in cross-section, and of length δh at the higher level. The small difference of pressure between the two ends of the cylinder is equal to the weight of the cylinder. Hence, if Δ_1 is the density at height h centimetres,

$$\frac{dp}{dh}\,\delta h = -\,\delta h \cdot \Delta_1 \cdot g$$

where g is the gravitation constant in centimetres per second per second. At standard pressure p, let the density be Δ, so that

$$\Delta_1 = \Delta \frac{p_1}{p};$$

therefore

$$\frac{dp}{dh} = -\,\Delta \frac{p_1}{p}\, g.$$

Integrating between $h = 0$ and $h = h$,

$$\int_{p_0}^{p_1} \frac{dp_1}{p_1} = -\,\Delta \frac{g}{p} \int_0^h dh,$$

the solution of which is

$$\log_e \frac{p_0}{p_1} = \Delta \frac{gh}{p};$$

or

$$h = 2\cdot3026\, \frac{p}{\Delta g} \cdot \log_{10} \frac{p_0}{p_1}.$$

The density of dry[1] air at t° C. and pressure p dynes per square centimetre is

$$\Delta = \frac{p \times 1\cdot2759 \times 10^{-9}}{(1 + 0\cdot00366\, t)}$$

and

$$g = 981;$$

therefore

$$h = \frac{2\cdot3026 \times (1 + 0\cdot00366\, t)}{1\cdot2759 \times 10^{-9} \times 981} \log_{10} \frac{p_0}{p_1}$$

$$= 1{,}839{,}640\,(1 + 0\cdot00366\, t) \log_{10} \frac{p_0}{p_1};$$

or, if F is the height of the ascent in feet,

$$F = 60{,}355\,(1 + 0\cdot00366\, t) \log_{10} \frac{p_0}{p_1} \quad . \quad . \ (1)$$

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[1] Everett's "Units and Physical Constants," fifth edition, pp. 43–47.

This enables a height-scale to be constructed for any average temperature t between the two extreme levels. To find the error δ F corresponding with a small error in the estimation of p_1, put $t = 0$, and differentiate. As, in general, the height-scale will be accurately set, it can be assumed—except in the case of storms—that there is no error in p_0. When differentiating equation (1), therefore, p_0 may be regarded as constant. Then—

$$\delta \mathrm{F} = -\frac{60{,}355}{2 \cdot 3026} \cdot \frac{\delta p_1}{p_1} = -26{,}215 \frac{\delta p_1}{p_1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The negative sign implies that when p_1 is estimated too low the altitude measurement deduced from the height-scale is too great, and vice versa.

Example.—Let the height-scale be supposed to be accurately graduated upon a 30-inch basis. It then reads accurately when the barometer at the lower level is 30 inches, and when the zero of the height-scale is correctly set to the 30 mark on the barometer scale. In equation (1) put $\mathrm{F} = 9{,}000$, and $p_0 = 30$. This gives $p_1 = 21 \cdot 281$. Again, in equation (1), put $\mathrm{F} = 9{,}000$ and $p_0 = 31$. This gives $p_1 = 21 \cdot 991$. The distances traversed by the pointer of the instrument in the two cases are equivalent to $30 - 21 \cdot 281 = 8 \cdot 719$ inches, and $31 - 21 \cdot 991 = 9 \cdot 009$ inches, respectively. By the use of a height-scale these differences are assumed to be equal, and there is a consequent error $\delta p = 9 \cdot 009 - 8 \cdot 719 = 0 \cdot 290$ inch. Hence, approximately, the error in the height measurement with the use of the height-scale is, from equation (2)—

$$\delta \mathrm{F} = -26{,}215 \frac{0 \cdot 290}{21 \cdot 991} = -346 \text{ feet.}$$

In this case p was indicated too low; hence the true height is 8,654 feet.

Temperature Error.—If the temperature term is added to equation (1) it may be expressed as—

$$\mathrm{F} = (1 + 0 \cdot 00366\, t) \times 60{,}355 \log_{10} \frac{p_1}{p_2}.$$

Hence—

$$\frac{d\,\mathrm{F}}{d\,t} = 220 \cdot 9 \log_{10} \frac{p_1}{p_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In Table I the values of $\log_{10} \frac{p_1}{p_2}$ are given for successive values of F, and the error in F due to an error of 1° in t can, therefore, be written down at once from equation (3). For example, at 9,000 feet $\log_{10} \frac{p_1}{p_2} = 0 \cdot 149121$, and—

$$\frac{d\,\mathrm{F}}{d\,t} = 220 \cdot 9 \times 0 \cdot 1491 = 32 \cdot 9 \text{ feet.}$$

It follows that the instrument error due to height-scale at 9,000 feet, which was found to be about 346 feet, is approximately equivalent to an error of 10° C. in estimating the mean temperature throughout the height.

In the following Table I the values are given from which the curves in *Fig. 1* were plotted. This Table also gives values of $\log_{10} \frac{p_1}{p_2}$ for estimating the temperature correction.

TABLE I.

True Height F.	$\frac{F}{60,355} = \log_{10} \frac{p_1}{p_2}$ from equation (1).	Ratio of Barometric Readings.		Barometric Readings at Higher Level, when Reading at Lower Level is 28, 29, 30 or 31 respectively.			
		$\frac{p_1}{p_2}$	$\frac{p_2}{p_1}$	$28 \frac{p_2}{p_1}$	$29 \frac{p_2}{p_1}$	$30 \frac{p_2}{p_1}$	$31 \frac{p_2}{p_1}$
Feet.				Inches.	Inches.	Inches.	Inches.
0	0	1·0000	1·00000	28·00	29·00	30·00	31·00
10	0·00016569	1·0004	0·99962	27·99	28·99	29·99	30·99
100	0·0016569	1·0038	0·99619	27·89	28·89	29·89	30·88
1,000	0·016569	1·0389	0·96257	26·95	27·91	28·88	29·81
2,000	0·033139	1·0793	0·92653	25·94	26·87	27·80	28·72
3,000	0·049707	1·1213	0·89185	24·97	25·86	26·76	27·65
4,000	0·066278	1·1649	0·85846	24·04	24·89	25·76	26·61
5,000	0·082845	1·2102	0·82663	23·15	23·97	24·80	25·63
6,000	0·099414	1·2572	0·79540	22·27	23·07	23·86	24·66
7,000	0·115983	1·3061	0·76563	21·44	22·20	22·97	23·73
8,000	0·132556	1·3569	0·73696	20·63	21·37	22·11	22·85
9,000	0·149121	1·4097	0·70938	19·86	20·57	21·281	21·99
10,000	0·165690	1·4645	0·68283	19·12	19·80	20·49	21·17
11,000	0·182259	1·5215	0·65727	18·40	19·06	19·82	20·38
12,000	0·198828	1·5806	0·63266	17·71	18·34	18·98	19·61
13,000	0·215397	1·6421	0·60898	17·05	17·66	18·27	18·88
14,000	0·231966	1·7060	0·58618	16·41	17·00	17·59	18·17
15,000	0·248535	1·7723	0·56424	15·80	16·36	16·93	17·49

TABLE II.—HEIGHT READINGS FROM AN ACTUAL BAROMETER.

Height-Scale Zero set at 30-Mark on Barometer-Scale.			Height-Scale Zero set at 31-Mark on Barometer-Scale.		
Instrument-Height Reading.	Instrument-Pressure Reading.	True Pressure from Equation 1.	Instrument-Height Reading.	Instrument-Pressure Reading.	True Pressure from Equation 1.
Feet.	Inches.	Inches.	Feet.	Inches.	Inches.
0	30·00	30·00	0	31·00	31·00
1,000	28·67	28·88	1,000	29·88	29·84
2,000	27·62	27·80	2,000	28·80	28·72
3,000	26·55	26·76	3,000	27·76	27·65
4,000	25·60	25·76	4,000	26·76	26·61
5,000	24·63	24·80	5,000	25·80	25·63
6,000	23·67	23·86	6,000	24·875	24·66
7,000	22·77	22·97	7,000	23·98	23·73
8,000	21·95	22·11	8,000	23·13	22·845
9,000	21·08	21·282	9,000	22·275	21·99
			10,000	21·475	21·17

OBITUARY.

WILLIAM NEWTON BAKEWELL, born on the 26th October, 1845, died at Keswick on the 3rd November, 1913. Trained at the Don Engineering Works, Rotherham, he was afterwards engaged on railways in the London district and on various public works in Egypt. During the erection of the Forth Bridge, he acted as contractor's engineer for part of the time, and later he was engaged in a similar capacity on the Tower Bridge, the Assuan Dam, the English bridge at Cairo, and irrigation schemes in Asia Minor. Shortly before his recent retirement, he surveyed harbours at Trebizond and Samsun, on the Black Sea, for Sir John Jackson.

Mr. Bakewell was elected a Member of The Institution on the 15th May, 1888.

JOHN BARKER, born at Sandiacre, Derbyshire, in 1842, died at Sutton Coldfield on the 21st October, 1913. He gained experience under the late Sir George Berkley, Past-President, and subsequently served under his successors, Sir George B. Bruce, Past-President, and Mr. R. White, M. Inst. C.E., for 43 years, as head of the Consulting Engineer's department of the Great Indian Peninsular Railway, in which capacity he was responsible for inspection of material, specifications and general supervision of work. He was also associated with the work for the Cape and Natal railways.

Mr. Barker was elected an Associate of The Institution on the 4th March, 1873, and was transferred to the class of Members on the 27th November, 1877.

JAMES RICHARD BELL died at Ightham, Kent, on the 14th July, 1913. Born at Wick in 1841, he joined the Indian Public Works service in 1868. At first employed in the Madras

Presidency, he was later transferred to the State Railways department of India, in which service he remained until his retirement in 1896. He gained a high reputation in the construction of bridges, amongst the more notable structures erected by him being the Empress bridge over the Sutlej,[1] the Muttra bridge across the Jumna, Ferozepur bridge and the Sher Shah bridge over the Chenab. He also devised successful means for training rivers by means of bunds. He carried out a large number of difficult surveys and constructed many miles of railway on the North Western, East Coast, Indus Valley and other systems, but perhaps his most important service to India was the construction, in a remarkably short time, of the line from Ruk to Bolan, giving military access to Kabul. Mr. Bell was for several years Consulting Engineer to Government for State railways.

He was elected a Member of The Institution on the 2nd December, 1879.

OSBERT CHADWICK, C.M.G., son of Sir Edwin Chadwick, was born on the 5th April, 1844, and died in Scotland on the 27th September, 1913. Educated at the Royal Military Academy, Woolwich, he entered the Royal Engineers in 1864, but resigned his commission 10 years later to become a civil engineer. Like his father, he adopted the sanitary branch of the profession, and for many years, as Consulting Engineer to the Colonial Office, he carried out many important sanitary works, chiefly in the Crown Colonies. These included water-supply, sewerage and drainage systems for Grenada, Malta, Hong Kong, Mauritius, Trinidad, Kingston, Jamaica, and many other places. His services were rewarded with a C.M.G. in 1886.

Mr. Chadwick was elected an Associate of The Institution on the 9th January, 1872, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 30th November, 1897.

JOHN COATES, born in 1846, died in London on the 10th February, 1914. Educated at Newcastle-on-Tyne, he received his engineering training at Lord Armstrong's Elswick Works, and was subsequently employed for 10 years on the staff of Messrs. Thomas and Charles Hawksley, of Westminster. In 1878 he commenced private practice in London, as engineer to Messrs. J. Abbott and Company, hydraulic engineers, of Gateshead, and other firms. In 1885 he visited Australia and opened an office in Melbourne, and later he extended his operations to Canada. He was responsible for gasworks and hydraulic-power installations at many towns in Europe, South America, Australia, and Canada, and as head of the firm of John Coates and Company, Ltd., he was a consulting and inspecting engineer to the Victorian State Railways, the Commonwealth Government, and to various public authorities and private corporations.

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[1] Minutes of Proceedings Inst. C.E., vol. lxv, p. 242.

Mr. Coates was elected an Associate of The Institution on the 7th December, 1875, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 13th March, 1888.

MICHAEL ELLIOT, born at Lilleshall, Shropshire, on the 23rd November, 1858, died at Malvern, near Melbourne, Australia, on the 4th June, 1913. After studying at Glasgow University and gaining practical experience, he went to Egypt in 1882 and was employed on irrigation and railway works. In 1887 he went to Australia, and after some years' service under the Victorian Government he engaged in consulting practice in Melbourne, and was responsible for a number of important irrigation, water-supply and drainage works in Victoria and for the Taieri Plain irrigation scheme in New Zealand.

Mr. Elliot was elected an Associate Member of The Institution on the 29th May, 1890, and was transferred to the class of Members on the 6th February, 1906.

HARRY HORNE ELLIOTT, second son of the late Sir Charles Elliott, was born on the 19th February, 1868, and died at Cape Town on the 31st January, 1914. Educated at the South African College, and trained under Mr. Melville as a Land Surveyor, he entered the Cape Government Railways service in 1888. He held charge of various sections of line, and in 1904 became Resident Engineer of the western system. In September, 1910, Mr. Elliott was appointed Maintenance Engineer of the

Cape Government Railways, and held that appointment at the time of his death.

He was elected an Associate Member of The Institution on the 6th February, 1894, and was transferred to the class of Members on the 10th January, 1911.

WILLIAM FOX, born at Plymouth in 1847, died at Upper Norwood on the 14th June, 1913, aged 66. Trained under Mr. J. F. La Trobe Bateman, Past-President, he remained with him until 1889, after which he commenced consulting practice in Westminster. In that capacity he designed and carried out water-supply and sewerage works for Douglas, Bath, Gloucester, Aberdare, Mountain Ash, Port Talbot, and other places. He also designed similar works for Vera Cruz and Tampico, and reported upon water-supplies for Teneriffe and Aberdeen. He was retained by the London County Council in connection with the Welsh water scheme, and also acted on behalf of other public bodies.

Mr. Fox was elected a Member of The Institution on the 4th December, 1877.

JAMES GRANT FRASER, younger son of Captain Fraser of the "Black Watch," was born at Nairn on the 8th April, 1825, and died at Horsham on the 30th December, 1913. Educated at St. Andrews University, and abandoning preparation for the Army in favour of engineering, he became a pupil with Messrs. Locke and Errington, civil engineers, being chiefly occupied on Mr. Locke's work. After completing his pupilage, he was engaged successively, as assistant or resident engineer, on the Basingstoke and Salisbury, Salisbury and Yeovil, Royston and Hitchin, and other branch railways. He was also on the Dutch Rhenish railways. In later years he was occupied chiefly in making valuations and giving evidence in rating cases.

Mr. Fraser was elected on the 6th May, 1862, a Member of The Institution, with which he was thus connected upwards of 50 years.

EDMOND RICH GABBETT, born at Corbally, Limerick, on the 28th February, 1852, died at St. Leonards on the 24th January, 1914. He served his apprenticeship at the locomotive works of Messrs. Robert Stephenson and Company, Newcastle-on-Tyne, and in 1876 was appointed Chief Engineer to Messrs. Burt, Boulton and Haywood, to which office he subsequently added the duties of General Manager of works, retaining both until his death. In this dual capacity he was responsible for the extensive works of the firm, and for their fleet of steamers. Among other ingenious devices he invented the Gabbett mixer for fluids.

Mr. Gabbett was elected an Associate of The Institution on the 6th February, 1877, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 8th December, 1891.

JAMES GRESHAM, born at Newark on the 28th December, 1836, died at Ashton-on-Mersey on the 13th January, 1914. Trained under Mr. W. White, of Newark, Sir William Fairbairn and Messrs. Sharp, Stewart and Company, he became, in 1866, head of the firm of Messrs. Gresham and Craven, manufacturers of railway machinery at Manchester, and continued to direct its affairs until his death. He invented various improvements in brakes, injectors and other appliances, and was an enthusiastic art-collector.

Mr. Gresham was elected a Member of The Institution on the 1st December, 1885.

JAMES HOWDEN, born at Prestonpans in 1832, died in Glasgow on the 21st November, 1913. He served his apprenticeship to Messrs. James Gray and Company, of that city, and after a brief interval set up in business for himself as a marine engineer. In 1862 he founded the firm of James Howden and Company, of which he retained the direction until his death. He designed and constructed marine engines and boilers for many of the largest steamship lines, and was the author of a long series of valuable inventions or improvements in water-tube boilers, high-speed engines and turbines, and notably of the Howden hot-air forced-draught system now generally adopted in the mercantile marine. A great variety of machinery was manufactured by the firm, and the works were rebuilt and considerably extended as their output increased. He also contributed many Papers to technical societies of which he was a member.

Mr. Howden was elected a Member of The Institution on the 5th April, 1892.

CHRISTOPHER CLARKE HUTCHINSON, K.C., born in 1854, obtained his engineering training with Messrs. Fairbairn, Kennedy and Naylor, of Leeds, and in 1880 became technical partner in the firm of S. H. Johnson and Company, mechanical and chemical engineers, of Stratford. For 16 years he was actively associated with the design and construction of sewage-disposal plant, air-compressors and chemical machinery generally. In 1896 he gave up engineering pursuits in favour of the law, being called to the Bar at the Middle Temple in that year. He quickly became a prominent member of the Parliamentary Bar, where his scientific training proved of great service, and was made a King's Counsel in 1910. He died at South Kensington on the 7th March, 1914.

Mr. Hutchinson was elected a Member of The Institution on the 12th January, 1897.

JOHN WILLIAM INGLIS, died in Edinburgh on the 13th March, 1914, aged 76. His professional career was passed entirely in India, where, after serving 4 years on the East Indian Railway, he entered the Public Works Department in 1862. He was successively employed on roads, bridges and other works, at Lucknow, Fyzabad, in Burma and in the North West Provinces, where he had charge of the Agra canal works and of the Lower Ganges canal works. He retired in 1880 with the rank of Executive Engineer. He had served through the Indian Mutiny, having joined the Volunteers in 1857.

Mr. Inglis was elected an Associate of The Institution on the 10th January, 1871, and was transferred to the class of Members on the 27th November, 1877.

CHARLES JONES, born at Beccles, Suffolk, on the 13th March, 1830, died at Ealing on the 24th August, 1913. After receiving a municipal training, and practising for a time as an architect, he was appointed Engineer and Surveyor to Ealing Local Board in 1863, retaining this office under the Borough Council until his death. The urban development of the district necessitated many engineering works, which Mr. Jones carried out in addition to acting as Consulting Engineer to many other local authorities.

Mr. Jones was elected an Associate of The Institution on the 2nd February, 1875, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 3rd November, 1891.

GEORGE WILLIAM KEELING died at Cheltenham on the 21st June, 1913, aged 74. He was trained under the late Mr. Thomas Blackwell, whom he afterwards succeeded as engineer of the Severn and Wye goods line, which he extended and converted to passenger traffic in 1875, thus opening up the Forest of Dean. On the absorption of the line in the Great Western and Midland systems, Mr. Keeling became engineer of the Gloucester and Hereford division of the Great Western Railway, and also for some years carried on private practice.

Mr. Keeling was elected a Member of The Institution on the 20th May, 1873.

FREDERICK KENSINGTON, born in London in 1838, died at Caterham on the 2nd March, 1914. After serving a pupilage to the late Mr. F. Parke, of Preston, he pursued a varied engineering career, chiefly in constructional and mining work, both at home and abroad. Amongst other work, he was engaged on railway construction and bridge erection in England, Austria, Spain, India and the United States, oil-boring in Galicia and Poland, the design and erection of mining machinery, and miscellaneous consulting work in London. He was the author of several Papers on mining and other subjects.[1]

Mr. Kensington was elected an Associate Member of The Institution on the 3rd April, 1892, and was transferred to the class of Members on the 24th November, 1896.

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[1] *Vide*, e.g., Minutes of Proceedings Inst. C.E., vol. cxvi, p. 327.

GEORGE EDWARD ORMISTON, born on the 8th February, 1844, at Glasgow, died at Kensington on the 3rd October, 1913. After gaining valuable experience of dock work at Cardiff and on the Surrey Commercial Docks, he entered the service of the Indian Public Works Department in 1870. On the formation of the Bombay Port Trust in 1873 he joined the engineering staff, under his brother, the late Mr. Thomas Ormiston,[1] the first Chief Engineer. Later he became resident engineer, and on his brother's retirement in 1882 succeeded him as Chief Engineer, a post which he held until his own retirement, owing to ill-health, in 1892. He was responsible for the Victoria and Prince's docks, Merewether dry dock, the Apollo Bunder extension, and many other important works.

Mr. Ormiston was elected an Associate of The Institution on the 20th May, 1873, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 4th November, 1879.

PETER ALEXANDER PETERSON, born at Niagara in 1839, died at Montreal on the 21st November, 1913. Trained under Mr. T. C. Keefer, he was subsequently occupied for several years on railway and other works in Canada and the United States, notably on the Intercolonial Railway and, as Chief Engineer, on the Toronto Waterworks. He then joined the staff of the Canadian Pacific Railway, and in 1890 was appointed Engineer-in-Chief of the system. In this capacity he carried out many important extensions and improvements, and designed and built the bridge across the St. Lawrence at Montreal. He had been in retirement for several years owing to ill-health.

Mr. Peterson was elected a Member of The Institution on the 1st December, 1874.

CHRISTOPHER EDWARD PHIPPS, born at Devizes on the 17th October, 1847, died at Ealing on the 22nd May, 1914. Educated at Uppingham and apprenticed to Messrs. Sharp, Stewart and Company, he afterwards obtained an appointment on the Madras Railway and left for India in 1871. He obtained rapid promotion in the Company's service, until he was appointed

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[1] Minutes of Proceedings Inst. C.E., vol. lxxi, p. 409.

Locomotive Superintendent, a position which he held until his retirement in 1902.

Mr. Phipps was elected a Member of The Institution on the 6th December, 1892.

SIR WILLIAM HENRY PREECE, K.C.B., F.R.S., Past-President Inst. C.E., and formerly Engineer-in-Chief of the Post Office, died at Penrhos, Carnarvon, on the 6th November, 1913, in his eightieth year. Born at Bryn Helen, Carnarvon, on the 15th February, 1834, he was educated at King's College, London, and gained practical experience in the offices of the late Edwin and Latimer Clark, then engineers to the Electric Telegraph Company. In 1853 Preece joined the staff of that company, which subsequently became by amalgamation the Electrical and International Telegraph Company, and after rapid promotion was appointed Superintendent of the Southern Division. From 1858 to 1862 he was also Engineer to the Channel Islands Telegraph Company, and in 1860 he became Superintendent of Telegraphs on the London and South Western Railway, where he introduced the Preece block system of working single lines and a system of electric communication between passengers and guard. When in 1870 the business of the various telegraph companies (about thirty in number) was transferred to the State, the subject of this memoir was appointed Engineer for the Southern Division of the State system with headquarters at Southampton. In 1877 he was appointed Electrician to the Post Office, and in 1892 he became in addition Engineer-in-Chief. He held this combined office until his retirement under the age rule in 1899, when he was appointed Consulting Engineer to the Post Office. In 1904 he resigned this office and devoted himself entirely to private practice in Westminster, in conjunction with Major Cardew and with two of his sons, Llewellyn and Arthur Preece. For his services to the nation he received a C.B. in 1894, and was created K.C.B. on his retirement in 1899.

As an investigator and inventor in the fields of electricity, telegraphy and telephony, Sir William Preece's record is one of sound and varied achievement. In earlier years he patented various systems of railway signalling and duplex telegraphy. His later work was connected with the improvement and perfecting of telegraphic apparatus, the introduction into this country of the telephone and the invention of several important improvements, and the origination of a method of signalling across space by induction telegraphy. On several occasions when cables failed between mainland and various islands he was enabled to transmit messages by means of parallel wires. When Mr. Marconi came to England Sir William Preece gave him every encouragement and support, and secured for him many important facilities from the Post Office for the prosecution of his work. He also introduced many improvements in the Post Office telegraphic system, carried out experiments on copper wires, and commenced to lay down cables for the trunk lines, a work completed by his successor. He made several official journeys to the United States and Canada, and also visited France, Germany, Austria, Italy and other European countries. He served on several Royal Commissions, and was a member of many conferences, exhibition committees, and other bodies. Among other offices, he twice held the presidency of the Institution of Electrical Engineers, was Chairman of Council of the Royal Society of Arts, President of the Mechanical Science section of the British Association, Fellow of the Royal Society, and a member of many other scientific and technical bodies. He was elected to the Council of The Institution in 1884, and became President in 1898, when his presidential address dealt with the development of electricity. He also delivered the "James Forrest" lecture in 1900 on the relations between electricity and engineering, contributed several Papers and Conference Notes to the Proceedings, and participated in many discussions at The Institution.

As an author, Sir William Preece was responsible, singly or in collaboration with others, for several standard works and a number of papers presented to various societies. In conjunction with Sir James Sivewright he wrote a well-known "Manual of Telegraphy," a book on "The Telephone" with Dr. Julius Maier, and a "Manual of Telephony" in collaboration with Mr. A. J. Stubbs. Possessing in a high degree the faculty of lucid and attractive exposition, he achieved considerable popularity as a lecturer, and was also a frequent and ready speaker at scientific meetings. His genial disposition attracted many friends and led him to take especial pleasure in encouraging young engineers at the outset of their career. A few years before his death failing health obliged him to curtail his varied activities and to seek the comparative seclusion of his native town, Carnarvon, where he ended his days after a long, strenuous and distinguished career.

Sir William Preece was elected an Associate of The Institution on the 24th May, 1859, and was transferred to the class of Members on the 5th December, 1871.

GEORGE RANKIN, born in Canada in 1858, died in London on the 4th January, 1914. He served a pupilage to his father, the late Mr. W. H. Rankin, and was subsequently employed on the Cape Government Railways. He then acted as contractor's engineer on the Buenos Aires harbour works, and after fulfilling engagements at Bermuda dockyard and Table Bay harbour, he was occupied on surveys for the Buenos Aires and Pacific Railway.

Mr. Rankin was elected an Associate Member of The Institution on the 1st April, 1884, and was transferred to the class of Members on the 24th January, 1905.

JAMES RICHMOND, C.M.G., born at Lochwinnoch, Renfrew, on the 29th July, 1849, died in London on the 20th March, 1914. As a pupil of the late Mr. Daniel Climie, he gained experience of railway and constructional work. In 1870 he went out to Jamaica on survey and irrigation work, and in 1873 entered the public service as senior assistant engineer for irrigation. Later he was appointed District and Irrigation Engineer, and in 1891 Assistant Director of Public Works. He constructed roads, bridges, buildings, sewerage systems and other public works. In 1900 he was appointed Director of the Government Railway, which he controlled for 13 years, retiring in 1913. He was a member of the Privy Council of Jamaica, and was made a C.M.G. in 1906.

Mr. Richmond was elected an Associate of The Institution on the 2nd May, 1876, was subsequently placed among the Associate Members, and was transferred to the class of Members on the 3rd November, 1891.

JAMES DIX SCHUYLER, born at Ithaca, New York, on the 11th May, 1849, died at Ocean Park, California, on the 13th September, 1912, aged 63. He was educated at the Friends' College, New York, and subsequently gained practical experience on railway surveys and construction in Colorado and other Western States.

In 1878 he was appointed Chief Assistant State Engineer of California, and was placed in charge of irrigation work, a branch of engineering in which he attained high distinction. He left the State Department in 1882 to become Chief Engineer of the Sinaloa and Durango Railway in Mexico, and on his return to California he constructed a portion of the sea-wall and sewers of San Francisco. His most important work at this time, and one which brought him rapidly to the forefront of his profession in America, was the design and construction of the Sweetwater Dam for San Diego, California. Among other works which he constructed were the Hemet dam, waterworks at Portland and Denver, the Bear River canal, Ogden waterworks, and a number of irrigation works throughout the West. As a consulting engineer he was associated with works of magnitude in all quarters of the western hemisphere. He was a member of the second Engineering Commission on the Panama Canal project, Consulting Engineer to the Government of Hawaii, to the Monterey Waterworks and Sewer Company, to the Kobe Syndicate, Japan, to the Mexican Light and Power Company, to the Vancouver Power Company, and to many other organizations and local bodies, chiefly in connection with water-supply, power, and irrigation works. He was the author of many scientific and technical memoirs and papers, probably his best-known work being "Reservoirs for Irrigation, Water Power, and Domestic Water-Supply," which ran through several editions, and was recognized as a standard text-book upon the subject. He was a member and vice-president of the American Society of Civil Engineers, and a member of the American Geographical Society, the Franklin Institute, and other societies. Bold yet prudent as an engineer, tolerant, kindly and patient, his sterling personal qualities endeared him to a large circle of friends in professional and social life, and his death is a loss to engineering both in America and in this country.

Mr. Schuyler was elected a Member of The Institution on the 3rd February, 1891.

THOMAS FRAME THOMSON died, as the result of an accident, at his residence, Caen Wood Towers, Highgate, on the 30th September, 1913, aged 46 years. By the accidental discharge of a sporting gun, from which he had intended to extract the cartridges before leaving home for South America, he was found shot through the heart in his dressing-room, a career full of solid and varied achievement and of still more brilliant promise being thus brought to an untimely close.

Born on the 19th May, 1867, he was educated at Kelvinside Academy, Glasgow, and Herbertshire Castle, Stirlingshire. At the age of 17 he became a pupil of Mr. John Strain, Vice-President Inst. C.E., whom he afterwards served as an engineering assistant. From 1888 to 1891 he acted first as Resident Engineer on the Lanarkshire and Ayrshire Railway and subsequently as Engineer, ably defending the company, at the early age of 23, in actions brought by the contractors in relation to the works. From 1890 to 1895, as a partner in the firm of Strain, Robertson and Thomson, Civil Engineers, of Glasgow and Westminster, he had charge of the London interests of the firm. Retiring from the firm in the latter year, he was occupied until February, 1896, in studying the construction and working of the railways of Argentina, an investigation which he carried out with characteristic ability and thoroughness. He then engaged in consulting practice in the City of London, amongst other important business visiting South Africa to study transport facilities and water-power for the development of white marble quarries, and South America to report on an extensive railway and port project, of which he became consulting engineer. He was a director of many important electric light, power, tramway, and other undertakings in Argentina, Uruguay and Brazil, and Chairman of the Otis Steel Company, of Cleveland, Ohio.

His extensive financial interests led him to recognize the importance to engineers of legal and commercial knowledge, the successful use of which was so ably exemplified in his own career. As evidence of the warm interest which he always felt in the welfare of young engineers, Students of The Institution, an interest maintained from his own student days in Glasgow until his death, he founded in 1910 a series of lectures to be delivered annually to the Students in London during his lifetime. The first three lectures on "The Commercial and Technical Relations of Engineering Design and Work," "The Principles and Practice of Accountancy," and "Law in Relation to Engineering," he prepared and delivered himself with the thoroughness and clearness of exposition which distinguished all his work, and he had already requested Mr. A. A. Hudson, K.C., to give the fourth lecture on "Contracts" (subsequently delivered), when death cut short his career. Copies of the three lectures were distributed by him to all Students of The Institution and to many others. Acting in accordance with what would undoubtedly have been his wish, his widow afterwards presented his engineering instruments to London Students who had been associated with him, and a collection of engineering books to the Glasgow Association of Students, to which he had been attached in earlier life. He took part in various discussions at The Institution, and was preparing, at the time of his regretted death, a comprehensive account of the Buenos Aires tramway undertaking.

Mr. Thomson was elected an Associate Member of The Institution on the 16th May, 1893, and was transferred to the class of Members on the 22nd February, 1898.

IRWINE JOHN WHITTY, born at Kilrush, County Clare, on the 18th June, 1839, died at Bristol on the 22nd February, 1913. After completing his education at Queen's College, Cork, he served a pupilage with the late Mr. P. R. Roddy in the construction of the Cork and Limerick railways, and in 1863 joined the staff of the East Indian Railway, and served for 16 years in the development of that system. In 1879 he was appointed Chief Engineer for the construction of the Darjeeling and Himalaya Railway, on the completion of which he joined the staff of the Bengal-Nagpur Railway. He retired in 1889 with the rank of Executive Engineer.

Mr. Whitty was elected an Associate of The Institution on the 6th February, 1877, and was transferred to the class of Members on the 30th October, 1877.

JAMES PICKLES WILKINSON died at Marple on the 31st March, 1914, aged 62. Having served his articles with Mr. Richard Horsfall, of Halifax, he became Engineer to the Newton Heath Local Board in 1881. When the district was absorbed into the City of Manchester in 1890 he passed into the service of the Corporation, and was engaged on the main drainage scheme and its extensions. In 1898 he commenced private practice and designed the extensive works for the biological treatment of Manchester sewage at Davyhulme, as well as sewerage and sewage-disposal works for many local bodies and for the Admiralty.

Mr. Wilkinson was elected an Associate Member of The Institution on the 1st February, 1887, and was transferred to the class of Members on the 10th January, 1905.

JOHN WILLCOCKS, born at Mussoorie, India, on the 31st July, 1859, died at Ealing on the 21st August, 1913. After passing out first of his year from the Thomason Civil Engineering College, Roorkee, he entered the Indian Public Works Department in 1879, and passed almost his entire service of 30 years in the railway branch. Amongst other important appointments, he held the offices of Consulting Engineer for Railways to the Bombay Government, Junior Consulting Engineer for Railways, Calcutta, Engineer-in-Chief of the Nagda-Muttra State Railway, which he designed and constructed, and Agent in Burma of the Burma Railways Company. He resigned Government service in 1909 with the rank of Chief Engineer.

Mr. Willcocks was elected a Member of The Institution on the 13th January, 1903.

EMANUEL ALOIS VON ZIFFER, born on the 23rd January, 1833, died at Vienna in October, 1913, aged 80. After undergoing a course of training at the Imperial Polytechnic School, Vienna, he was employed in the construction and maintenance of various railways in Austria, notably the Lemberg-Czernowitz-Jassy line, of the directorate of which he became President in 1875, with his office in London. Subsequently he constructed a number of local railways in Austria, becoming director and president of various railway undertakings, as well as of construction and equipment companies. He received several Austrian decorations, served on State Railway and other Commissions, and was a member of a number of technical societies.

He was elected a Member of The Institution on the 21st May, 1895.

ROBERT SANDERS ANDERSON, born on the 10th October, 1855, died at Peebles on the 30th November, 1913. He obtained his practical training on the North British Railway, and after some municipal work at Penicuik and in Edinburgh, he was appointed County Road Surveyor and Sanitary Inspector for Peeblesshire, a position which he held for 30 years.

Mr. Anderson was elected an Associate Member of The Institution on the 3rd May, 1881.

HUGH BATESON, born on the 20th June, 1870, died in London on the 14th March, 1914. Trained in the Locomotive Works at Crewe, and as a private pupil of the late Mr. F. W. Webb, he afterwards served on the London and North Western staff until 1895, when he obtained an appointment as Assistant Engineer on the Assam Bengal Railway. Subsequently he was employed as Executive Engineer on railway and bridge construction in the Punjab until his death.

Mr. Bateson was elected an Associate Member of The Institution on the 3rd December, 1895.

ALBERT WILLIAM CRAVEN, born in Yorkshire in 1855, died at Melbourne, Victoria, on the 28th November, 1913. Trained under Mr. J. B. Henderson, M. Inst. C.E., he afterwards engaged in consulting practice, in the course of which he carried out a number of surveys in difficult country, as well as mine-surveys and other work. He was for 24 years a member of the Victorian Legislative Assembly, and also for several years Chairman of the Standing Committee on Railways.

Mr. Craven was elected an Associate Member of The Institution on the 3rd March, 1891.

JOHN WILDING DAWSON, born on the 4th January, 1866, died in Mauritius on the 18th January, 1914. Trained under Mr. John Stevenson, of Barrow, he subsequently carried out building and railway work in British Columbia, and in 1894 he obtained an appointment as Resident Engineer on sewerage works at Port Louis, Mauritius. In 1904 he was appointed Assistant Director of Public Works and Surveys, and held this post at the time of his death.

Mr. Dawson was elected an Associate Member of The Institution on the 4th December, 1906.

ARTHUR FRANCIS EVES, M.A., M.A.I. (*Dubl.*), born on the 20th May, 1876, died at Cawnpore, India, on the 25th October, 1913. On leaving Trinity College, Dublin, he served a pupilage to Messrs.

Fisher and Le Fanu, Belfast, and to Messrs. Dick, Kerr and Company, London, for whom he subsequently acted as engineer on several tramway contracts. In 1906 he obtained an appointment with the East Indian Railway Company, which he retained until his death.

Mr. Eves was elected an Associate Member of The Institution on the 7th April, 1903.

SACKVILLE FISHER, born in 1859, died in Westminster on the 13th November, 1913. He served a pupilage to the late Mr. F. G. Slessor on the Cape Government Railways, and was afterwards on the contractors' staff of the Severn Tunnel works. Returning to Cape Colony in 1881, he was employed on the railways until 1884, after which he was engaged on the Manchester Ship Canal works, as an engineer on Messrs. Walker's staff, until 1890. Shortly afterwards his health broke down, and he retired from professional life.

Mr. Fisher was elected an Associate Member of The Institution on the 1st December, 1885.

JOHN-BAPTIST ROBERT GREEN, born on the 16th October, 1887, lost his life by drowning at Wadi Halfa, Sudan, on the 1st November, 1913. He was trained in the locomotive department of the London and North Western Railway at Crewe, and at the Great Northern works, Doncaster. At the time of his death he occupied the position of district locomotive superintendent on the Sudan Government railways.

Mr. Green was elected an Associate Member of The Institution on the 4th February, 1913.

EDWARD HODGSON, born on the 10th July, 1854, died at Sunderland on the 5th May, 1913. After serving a pupilage under Messrs. Joseph Potts and Son, of that city, he entered the service of the Sunderland Corporation as an assistant in the Engineer's department. At the time of his death he was acting as Deputy Borough Engineer, under Mr. J. W. Moncur, M. Inst. C.E., and had been associated with a great variety of municipal work carried out by the Corporation.

Mr. Hodgson was elected an Associate Member of The Institution on the 2nd April, 1901.

FREDERICK MACKINLAY, born on the 29th October, 1859, at Rosario, Argentina, received his practical training in England at the Thames Ironworks. In 1880 he returned to South America and entered the Railway Survey Department of Argentina. He was employed on the survey and construction of railways in the various provinces, and subsequently engaged in consulting practice in Buenos Aires, where he died on the 31st December, 1913.

Mr. Mackinlay was elected an Associate Member of The Institution on the 19th May, 1885.

RICHARD PROVIS, born at Camborne in 1862, died at Brighton on the 25th April, 1913. After gaining extensive experience of mining in Cornwall, he went out to Tasmania as Mining Engineer and Manager to the Tasmanian Land and Exploration Company, Limited, and subsequently acted in a similar capacity for the United Australian Exploration Company, Limited, and for the Orsk Goldfields Company in Russia.

Mr. Provis was elected an Associate Member of The Institution on the 6th December, 1887.

JAMES MELVILLE ROBERTSON, born on the 11th February, 1886, met his death as the result of an accident in Canada on the 14th September, 1913. Trained in Glasgow as a pupil of Messrs. Wharrie and Colledge, civil engineers, he afterwards went out to Canada, where he obtained employment on railways under construction. At the date of his untimely death he held the post of resident engineer on the construction of the Alberta Central Railway.

Mr. Robertson was elected an Associate Member of The Institution on the 6th February, 1912.

ARTHUR TOULMIN SMITH, born in 1848 at Highgate, died at Moscow on the 24th January, 1914. He received his practical training under Messrs. Siemens Brothers, and was afterwards employed by them on the construction and maintenance of the Indo-European telegraph line. In 1876 he was appointed manager to the Moscow Gasworks Company, and retained this position until the municipality acquired the undertaking. He then, as partner in the firm of Ludwig and Smith, became a manufacturing engineer in Moscow, and remained in this business until his death.

Mr. Smith was elected an Associate of The Institution on the 30th May, 1876, and was subsequently placed in the class of Associate Members.

LEONARD TEMPLE, born on the 3rd March, 1875, died at Worthing on the 19th December, 1913. He obtained his practical training at Messrs. Simpson and Company's works at Pimlico, and was subsequently employed for some years in the engineer's office of the Great Northern Railway at King's Cross. At the time of his death he was chief assistant to Mr. R. C. H. Davison, M. Inst. C.E., engaged on harbour, dock, and sea-defence work.

Mr. Temple was elected an Associate Member of The Institution on the 5th March, 1901.

THOMAS LISTER WALSH, born at Halifax on the 5th October, 1847, died at Hipperholme, near Halifax, on the 28th December, 1913. Apprenticed to his uncle, Mr. R. Horsfall, of that town, he was subsequently employed on railways in the Midlands and North. After fulfilling an appointment in New Zealand, he was engaged on New Street Station, Birmingham, and other works. Later he was employed by Messrs. S. Pearson and Sons, contractors, on the Sheffield sewage works, Southampton docks, Hudson River tunnels, New York, Mexico City drainage, Vera Cruz harbour, Seaham harbour, and other contracts. He retired owing to ill-health in 1902.

Mr. Walsh was elected an Associate Member of The Institution on the 4th December, 1894.

WILLIAM ROWAN WILSON, B.Sc. (*Glas.*), born on the 15th February, 1872, at Partick, Glasgow, died in that city on the 10th December, 1913. After assisting Lord Kelvin, he entered the Glasgow Corporation Electricity Department, under Mr. W. Arnot. In 1896 he became Engineer and Manager to Messrs. J. Fleming and Company, contractors, Bombay, and subsequently became Engineer and Manager of the New Egerton Woollen Mills, Punjab. In 1905 he entered the service of the Punjab Government as Executive Engineer, and subsequently held the post of Director of Industries in the United Provinces.

Mr. Wilson was elected an Associate Member of The Institution on the 8th January, 1907.

THOMAS BROWN YOUNGER, born at Leven, Fife, on the 15th December, 1850, died in London on the 30th August, 1913. Trained in the works of Messrs. H. Balfour and Company, Leven, he was subsequently employed at the London Gasworks, Nine Elms, and in 1876 went to Georgetown, Demerara, where for 20 years he acted as Engineer and Manager to the British Guiana Gas Company, and also carried on a consulting practice as engineer of water-supply undertakings, sugar estates, and other works.

Mr. Younger was elected an Associate Member of The Institution on the 5th December, 1882.

VINCENT WALKER HILL, M.V.O., formerly General Manager of the South Eastern and Chatham Railway, died at Folkestone on the 23rd November, 1913, aged 69. Born on the 6th February, 1844, he entered the service of the London, Chatham and Dover Railway as a junior clerk in 1862. Subsequently he became superintendent at Victoria Station, district superintendent, and Parliamentary assistant to the Chairman, the late Mr. J. Staats Forbes. In 1884 he was appointed Manager of the Hull and Barnsley Railway, a position which he occupied for 16 years, discharging in addition the duties of Secretary and conducting the undertaking successfully through a difficult period. In 1900 he was selected to succeed Mr. Alfred Willis as General Manager of the South Eastern and Chatham Railway, and during his tenure of that office considerable reorganization and improvements were carried out. Train services were revised, rolling-stock improved, and turbine steamers introduced on the cross-channel passages. On Mr. Hill's retirement in 1911 he was appointed a director of the South Eastern Railway and a member of the South Eastern and Chatham Managing Committee. He was a member of the Victorian Order and a Chevalier of the Royal Order of Isabel of Spain.

Mr. Hill was elected an Associate of The Institution on the 1st December, 1885.

JOHN PRICE, born on the 12th June, 1846, died at Wimbledon on the 25th June, 1913. In earlier life he was associated with the construction of the Metropolitan District, Barry, Cambrian and Kettering railways, the Severn and Sevenoaks tunnels, and held charge, as contractor's engineer, of six sections of the Manchester Ship Canal. In 1893, as a contractor in partnership with Mr. T. J. Reeves and Mr. C. J. Wills, he carried out contracts for the Central London, Hampstead, and Piccadilly tube railways, docks at Portsmouth, Newport, Immingham and Bombay, Fraserburgh and Heysham harbours, railways in Surrey, Lincolnshire and South Wales, Rotherhithe tunnel, and other important enterprises.

Mr. Price was elected an Associate of The Institution on the 7th December, 1897.

⁂ The following deaths have also been made known between the 28th February and the 31st July, 1914:—

Honorary Members.

The Right Hon. Joseph Chamberlain, P.C., F.R.S., M.P. ; *died* 2 July, 1914.

Noble, Alfred ; *died* 19 April, 1914.

Members.

Apjohn, James Henry ; *died* 4 April, 1914.

Barker, John ; *died* 14 July, 1914.

Bayliss, George Reginald ; *died* 2 June, 1914.

Brounger, Sydney George ; *died* 27 May, 1914.

Collins, Ernest ; *died* 20 April, 1914.

Crawford, *Professor* Robert ; *died* 31 May, 1914.

Dawson, George James Crosbie ; *died* 14 June, 1914.

Duquemin, James ; *died* 6 July, 1914.

Fowler, Alfred Mountain ; *died* 1 June, 1914.

Fox, Francis ; *died* 13 March, 1914.

Members—continued.

GRAY, ROBERT KAYE; *died* 28 April, 1914.

GRIFFITH, FREDERICK; *died* 22 March, 1914.

HACK, HENRY; *died* 2 January, 1914.

HALL, JOSEPH; *died* 7 May, 1914.

HARINGTON, HERBERT SEPTIMUS; *date of death unknown.*

JACOMB-HOOD, JOHN WYKEHAM; *died* 6 March, 1914.

MANNERING, HORACE JOHN; *died* 9 July, 1914.

MARTEN, EDWARD BINDON; *died* 8 June, 1914.

MENDES, EURICO DA COSTA; *died* 8 March, 1914.

MOORSOM, LEWIS HENRY; *died* 10 March, 1914.

NEWBIGGING, THOMAS; *died* 1 June, 1914.

NYSTROMER, CARL AUGUST BERNHARD; *died* 27 December, 1913.

RICHMOND, JAMES; *died* 20 March, 1914.

SCOTT, WILLIAM GEORGE; *died* 15 May, 1914.

STEWART, JAMES; *died* 12 February, 1914.

TAYLOR, WALTER; *died* 20 April, 1914.

TREWENT, FRANCIS JAMES; *died* 17 May, 1914.

WILLIAMS, MORGAN BRANSBY; *died* 21 June, 1914.

Associate Members.

BAYLISS, THOMAS RICHARD; *died* 24 July, 1914.

BULL, HARRY FREESTONE; *died* January, 1914.

JONES, COSMO REYNOLD; *died* 16 March, 1914.

KIRKALDY, WILLIAM GEORGE; *died* 10 April, 1914.

McEWEN, HUGH GORDON; *date of death unknown.*

PRICHARD, DAVID; *died* 7 February, 1914.

PRITCHARD, PHILIP MORRIS; *died* 8 July, 1914.

SUTTON, JOSEPH WALKER: *died* March, 1914.

VILLIERS, BERTRAM MONTAGU; *date of death unknown.*

WINDLE, JAMES FITZGERALD; *died* 17 April, 1914.

Associates.

BLISSETT, THOMAS; *died* 22 March, 1914.

DURNING-LAWRENCE, *Sir* EDWIN; *died* 21 April, 1914.

NOTMAN, HENRY WILKES; *died* 20 April, 1914.

SECT. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

Compression of Actual Gases. H. BROT.

(Revue de Mécanique, Paris, 1913, vol. 33, pp. 551-560.)

Van der Waals' relation for actual gases, namely:—$\left(p + \frac{a}{v^2}\right)(v - b) = \text{RT}$, is taken as the basis, and, combined with other usual thermodynamic relations, the following equation is obtained:—$d\text{Q} = \frac{\text{A}\,a}{v^2}\,d\,v + c\,d\,\text{T} + \text{A}\,p\,d\,v$, where Q is the quantity of heat absorbed, T the absolute temperature, and A the calorific equivalent of work. An investigation is then made of the general case resulting in the following expressions:—$\text{T}\,(v - b)^{\text{K} - 1} = \text{constant}$, and $\left(p + \frac{a}{v^2}\right)(v - b)^{\text{K}} = \text{constant}$, where K is $\frac{\text{A R} + c}{c}$, R being the gas constant, and c the variable specific heat at constant volume. From these equations it is shown that the work done is in some cases less and in some cases greater than it would be with a perfect gas, the reason being that the internal pressure of the gas on which the constant a of Van der Waals' expression depends reduces the amount of work required, whereas the "co-volume," namely, b in Van der Waals' expression, increases the amount of work.

H. R. S.

Topographical Surveys made by the American Section of the International Boundary Commission, United States and Mexico. W. W. FOLLETT.

(Proceedings of the American Society of Civil Engineers, New York, 1913, vol. 39, pp. 1821-1858.)

During the winter of 1910–1911 the Author and Mr. E. Zayas made a survey of the Rio Grande from Roma to the Gulf of Mexico. This survey covered an area of about 140 miles long and 2 to 3 miles wide, including the territory which is subject to the erosive action of the river. It was desired to obtain data for the construction of a map to a scale of 1 in 5,000. A precise line was run along the river, and at intervals of 2 to 3 miles small concrete reference-points were built and accurately located. From this precise line spurs were run to monuments on the "bancos." Stadia traverses were run, starting from, and closing on, some precisely located point. Also a primary line of levels was run from Roma to the gulf, and ordinary levels were run to determine the elevation of each hub on the stadia lines. There were five theodolite and two level parties in the field. The limits of error to which it was attempted to work were, 2 seconds in the angles on the precise line, 1 in 20,000 on the line, or 5 millimetres to the 100 metres. On the primary levels elevations should check within 0·008 metre $\sqrt{\text{distance in kilometres}}$. In 439 angles the average instrumental error was 0·162 second per angle, while the average distance-error was 1 in 91,000. The line was measured with a 100-metre tape, correction being made for temperature. The field operations lasted from the 1st October, 1910, to the 30th June, 1911, and, including all transportation charges and repairs to outfit, the cost was £4,610.

R. S. B.

Graphic Representation of Coloured Light. E. JASSÉ.

(Elektrotechnische Zeitschrift, Berlin, 1913, vol. 34, pp. 1454–1456.)

Block plotted the results of his work on coloured light by taking the ratio of red to green as ordinates and the ratio of blue to green as abscissas. Certain difficulties arising from this method are referred to, and the suggestion is made to employ Maxwell's triangle, in which the corners represent pure red, pure green and pure blue light. The centre represents pure white light, and any other point represents the proportion of red, green and blue present in any light-source by the length of the perpendiculars from the point to

	Red.	Green.	Blue.
Daylight	0·333	0·333	0·333
Town-gas, with Rami fibre mantles	0·575	0·281	0·144
Metal-filament lamp, working at 1·2 watt per Hefner candle	0·643	0·237	0·120
Metal-filament lamp, working at 0·5 watt per Hefner candle	0·554	0·276	0·170
Daylight arc-lamp.	0·483	0·305	0·212
Magnitite arc-lamp	0·382	0·333	0·285
Flame arc-lamp—white light	0·423	0·369	0·208
Flame arc-lamp—red light	0·770	0·141	0·089
Quartz-mercury vapour lamp with opal shade .	0·138	0·690	0·172
Moore light with CO_2.	0·290	0·342	0·368
Moore light with nitrogen	0·850	0·130	0·020

the sides of the triangle, the sum of which is constant and equal to the height of the triangle. The Author has re-calculated Block's experiments on this basis, and gives the results in a tabular form, and they are also plotted on Maxwell's triangle. Sunlight, with an overcast sky, is taken as the standard for white light. The Table on p. 379 gives some of the results.

H. R. S.

Characteristics of Enclosing Glassware. V. R. LANSINGH.

(Transactions of the Illuminating Engineering Society, New York, 1913, vol. 8, pp. 447-458.)

Numerous tests are described, made at three different laboratories, to determine the effect of the enclosing glass bowls and reflectors on the distribution, absorption, lamp and the colour of the light. There are now on the market nine different classes of such glassware, depending on the shape and on the material, which may be either opal, ground, or prismatic glass. A large number of photometric curves are given, together with tabular statistics, of the zonal flux obtained with these different classes, and with lamps of 100 and 200 watts, and they are compared with the results obtained with the bare lamp. It is deduced that there are two distinct classes of glassware, viz., ground glass and opal glass, which merely transmit and diffuse, and prismatic glass, which acts by spectacular reflection. In the former class the effect of the redistribution of the light is negligible, but there is some diffusion. With prismatic glass the distribution can be varied as may be required. The absorption of light is the same in all cases.

H. R. S.

Hertz Process for Testing Hardness.

DR. BRUNO SCHWARZE.

(Annalen für Gewerbe und Bauwesen, Berlin, 1913, vol. 73, pp. 81-85.)

The conditions under which the hardness of any substance can be ascertained and compared with that of other materials, by the use of metal spheres under pressure, were laid down by Henry Hertz in 1880. The Author's experiments relate only to the case in which the first substance is spherical and the second has a flat surface, and he instances mathematical definitions deduced from tests, by means of which he obtains formulas to calculate the hardness of the metal. It may be shown from Hertz that, provided the elastic limit of the metal is not exceeded, the proportion of the diameter of the metal ball to the third power of the diameter of the circle of depression is constant. The Author proposed to study the results when the elastic limit was exceeded, and to test the accuracy of the Hertz formula. The experiments were carried out with rolled crucible steel, the composition of which is given. A photograph shows the apparatus employed for the experiments. It was adapted to obtain loads of 500, 1,000, 1,500, 2,000, 2,500, and 3,000 kilograms, and the diameter of the ball was as usual 10 millimetres. The diameters of the depressions were measured by means of a Zeiss microscope, and it was possible by estimation to read to the thousandth part of a millimetre. Capt. Grard found that the depressions formed in rolled-iron plates were slightly elliptical in shape, and that the long diameter was parallel to the marks of the roll, and the short diameter at right angles to the same. The loading period was in all cases 15 seconds, and the load was applied vertically over the test-piece. Grard found small differences in the diameter consequent on the speed with which the loading was applied, and he suggested a uniform time of 2 minutes, which the Author thinks would unduly prolong the operations. The Author's results are set out in a table which gives tensile strength, percentage of elongation, and diameter of depressed circle, as observed and also as calculated by the formula. The differences of the last figures are very small.

G. R. R.

Calculations for Structures required to withstand Earthquake-Shocks.

(Giornale del Genio Civile, Rome, 1913, vol. 51, pp. 545–698.)

This is a report of the Royal Commission constituted in December, 1911, for the purpose of revising the regulations made in April, 1909, relating to structures subject to earthquake-disturbances. The report, which is too long and detailed for a general abstract, is divided into five parts, as follows:—(1) General notices; (2) Abbreviated methods of calculation; (3) Examples of calculations for structures to resist earthquake-shocks; (4) Numerical applications of calculations for stability against undulatory disturbances; (5) Illustrative notes on the theory and calculation of reinforcing networks. The report is illustrated by diagrams and drawings.

L. F. M.

Relations between the U.S. Bureau of Standards and Public Committees. E. B. Rosa.

(Electrical World, New York, 1913, vol. 62, pp. 941–942.)

The Author, who is the chief physicist of the U.S. Bureau of Standards, gives here an outline of the work of the Bureau and of the directions in which it co-operates and hopes to co-operate with the various Public Engineering Committees of the different States. One of the first of these problems studied was the preparation of specifications for the quality of illuminating gas and gas-service and methods of testing such gas. Another investigation concerned the electrolytic corrosion of gas- and water-pipes and lead cable-sheaths by earth-currents due to electric railways. A third investigation of practical importance was on the life-hazard in electrical work. Another was on the instruments used in electrical measurements and the methods of testing. The Bureau hopes to be of assistance to the Committee in collecting and investigating information bearing on the regulation of public undertakings by the Committees. It serves in some measure as a clearing-house for technical information, and in some degree as an agency for scientific and engineering investigations.

P. T. S.

New Automatic Fire-Alarm. F. A. J. Fitzgerald.

(Journal of the Franklin Institute, Philadelphia, 1913, vol. 176, pp. 575-582.)

The action of this fire-alarm depends on the use of a substance called thermitite, which has a large negative coefficient of electrical resistance. The material is made up in small flat plates, 10 millimetres long, 5 millimetres wide, and 0·5 millimetre thick, and copper wires are fused to each end. These small plates are mounted on glazed porcelain and the copper wires are soldered to contacts arranged like those of glow lamps. A wiring diagram is given showing a small transformer to reduce the voltage to 6 volts, and a number of thermoscopes are placed in parallel like glow lamps; the current passes continuously through them. Should the temperature of any one of the small plates be increased above the normal air-temperature by only a few degrees its resistance is diminished, which increases the current passing through it, causing heating of the strip and a further reduction of resistance. A "building-up" action thus takes place, quickly increasing the temperature of the strip, and so soon as this temperature reaches the critical point of 100° C. the resistance breaks down suddenly, and a sufficient current passes through to actuate an alarm-bell by means of a relay. Experiments show that polarization occurs, and for this reason an alternating current must be used. Experiments also show that a temperature of 5° C. above the normal temperature to which the thermoscope has been set will cause the apparatus to work. Several tests are described. The system is extremely simple, being equivalent to an ordinary bell-equipment.

H. R. S.

Extinguishing Fires in Oils and Volatile Liquids.

E. A. Barrier.

(Journal of the American Society of Mechanical Engineers, New York, 1913, vol. 35, pp. 1609–1616.)

It is stated that the only two methods which can be used in extinguishing fires in volatile oils are either to form a blanket of gas or solid matter over the burning liquid, or to dilute the burning liquid with an inflammable extinguishing agent which is miscible with it. For example, sawdust is effective, and an improvement is made by adding sodium bi-carbonate. The sawdust floats on the top of the oil and excludes the air. Carbon tetra-chloride forms a blanket of gas over the burning liquid and also dilutes the oil. The effectiveness of this method depends very much on the skill of the operator. In the case of gasolene a tank larger than 28 inches by 12 inches is rather more than one operator can deal with. In a test in which a tank 60 by 30 inches was used, no less than seven operators were needed to put out the fire. A frothy mixture has also been used, requiring two liquids (the nature of which is not disclosed), which are mixed and form a froth. Tests are reported, and in one case 5 tons of burning crude naphtha, and in another 13,000 square feet of burning tar, were extinguished.

H. R. S.

Heating and Ventilation of the Swiss National Bank Building in Bern. L. Greiner.

(Schweizerische Bauzeitung, Zürich, 1913, vol. 62, pp. 246–249, 255–259.)

As the result of a competition the heating and ventilation of the Swiss National Bank Building in Bern was entrusted to the Bern Central Heating Company. The installation consists of: (1) A forced-circulation hot-water apparatus for the warm-air heating and ventilation of the store-rooms in the basement; (2) a ventilating-plant for the halls and offices; (3) a gravity hot-water apparatus for the ground and upper floors; and (4) an air-cooling plant. Auxiliary to these are pneumatically-controlled air-inlets, a system of low-pressure air-gauges, and pneumatically-controlled temperature regulators. The air is changed in the halls, large offices, staircases and lavatories three times per hour, and in the smaller rooms three times in 2 hours; this rate can be maintained down to −20° C. external temperature for the entrance hall and lower floors, and down to −5° C. for the offices. The air-heating chambers are furnished with smooth radiators provided with auto-regulators. The air for the store-rooms is deprived of humidity to prevent condensation on the walls of the chambers. Cold town-water is passed through the radiators in summer to cool the air, and the water then passes to a cistern, whence it trickles over the glass roofs and supplies the W.C. cisterns. The floor of the boiler-house is 29·5 feet below street-level, the regulator-room next above, and the air-heating chamber again above. The fresh air is taken in high above street-level; the air-filter is of the "Schmidt" type. The radiators are all fed by low-pressure hot water on the gravity system as being the simplest in working and cheapest in upkeep. These are fed by three sectional boilers with a total of 884·5 square feet heating surface, and the coke is fed into the tops of the boilers by a skip travelling on a rolling way. The coke-room is filled with 150 tons once a year. The glass roof over the hall is double, with radiators between the two roofs, and the temperature is maintained there at 12° C. by the Johnson system of temperature-regulation. The whole of the controlling valves and all the regulating apparatus are collected together in one chamber just over the boilers. The fuel-consumption is less than calculated, and the installation has proved satisfactory. E. R. D.

Specification for Factory-Timbers. F. J. HOXIE.

(Journal of the American Society of Mechanical Engineers, New York, 1914, vol. 36, pp. 20–31.)

The Author calls attention to the fact that dry rot in the structure of mills in the Eastern States is rapidly increasing, owing to the use of inferior timber. Long-leaf pine was almost invariably used, but now short-leaf, Cuban and North Carolina pine are mostly employed. He is of opinion that specifications are not clearly drawn, and he gives some examples. He seeks to show that resistance to dry rot is due to the presence of resin, and to prove this contention many cross-sections of timber are photographically reproduced. A section of long-leaf pine shows a central region with 25 per cent. of resin, a middle region with 14 per cent., and an outer region with 3 per cent. Sections of pine beams removed after 2 years' service, and badly rotted away, are also given, and in these the rotted portion had under 1 per cent. of resin. The conclusion the Author derives is that 3 per cent. of resin is just sufficient to stop the growth of dry-rot fungus.

In the discussion Mr. Hermann von Schrenk denied the Author's resin theory, and attributed the dry rot merely to the presence of sap-wood. H. R. S.

Modern Designs in Timber and their Uses. OLAF J. ANDERSEN.

(Ingeniören, Copenhagen, 1914, pp. 9–13.)

The place of timber for permanent engineering structures has for many years gradually been taken by iron and steel, and it is only recently that serious efforts have been made to reinstate it by the adoption of improved designs based on a more correct knowledge of its properties and the application of modern methods of grouping the material effectively. Several systems have been developed, the principal characteristic of which is that the use of timber of large cross-sections has been abandoned, and that instead boards and battens of small scantling are joined together to make up the members of a structure. One class deals chiefly with lattice-work, another with more massive design. Of latticed designs, arches are hitherto most generally used with a main tie, or without one, where the arch springs from firm abutments. The arches have usually parallel flanges united by a lattice system. The flanges are made up of 1-inch to 2-inch thick battens, placed on edge vertically and bent edgewise to the required curve by a special process. The battens are connected together by numerous nails; the different layers break joint, and it is claimed that by this method a very homogeneous structure is obtained. The method of connecting the diagonal system is also described in detail. Roofs of up to 200 feet span have been built with perfectly satisfactory results. The solid construction also employs boards, $\frac{5}{8}$ inch to 1 inch thick, but placed horizontally and bent to curve on the flat as required. The various thicknesses are glued together by a special glue of great strength and stated to be unaffected by dryness and damp. The boards are carefully cleaned and coated with the glue, and assembled to form the required part, which is then placed in special presses, where it remains for 24 hours. On removal it retains its form and can be worked as a piece of solid timber. Great facility for varying the cross-section is obtained; a beam may be given thicker flanges at the middle, and an arch fined down towards the abutments, etc. Tests of completed structures have given excellent results after several months' exposure to the weather. As regards fire-danger, it is pointed out that a fire generally starts in the contents of a building and that an iron roof may fail at an early stage by the local overheating of one of its parts, whereas a timber roof holds up until its parts are practically burnt through. Examples of structures are described and illustrated, particularly the roof of the new passenger-station at Copenhagen.

L. S. Z.

Painting Structural Steel. A. H. SABIN.

(Proceedings of the American Society of Civil Engineers, New York, 1913, vol. 39, pp. 2061-2066.)

Red lead, which is an oxide of lead, makes an excellent paint for iron; oxide of iron is neither very good nor very bad; oxide of manganese is bad. Formerly the analyses of red lead showed as low as 55 per cent. of true red lead and 45 per cent. of litharge. As red lead is made from litharge, the presence of the latter is a sign of incomplete conversion. By fine grinding before roasting, red lead now contains as much as 94 per cent. of true red lead, and this means economy and better paint. The only serious objection to the use of such red lead is that it dries more slowly than the older kinds, but this can be obviated by a little japan-drier. The Author states that litharge is not the valuable part of the paint, as has sometimes been suggested. A Committee appointed by the American Society for Testing Materials has made a final report on the conditions of the paints on the Havre de Grace Bridge, which was painted about 6 years ago.[1] Three of these paints were excellent, two were pure red lead in oil, and the third was red lead with about 15 per cent. of a pulverized silicate added, the red lead being about 98 per cent. red lead. Nine other paints of varying composition are reported as affording effective protection to the structure.

R. S. B.

New Method of Reinforced-Concrete Construction.

F. SCHIERBECK.

(Ingeniören, Copenhagen, 1913, pp. 613–619.)

After pointing out the difficulties in the way of controlling the work during progress, the Author states that in his experience the failure of the connections between the reinforcing-bars is the most frequent cause of trouble. His efforts have therefore been specially directed to finding a trustworthy method of connecting the bars where they intersect or where they lie side by side. In this he thinks he has been successful by means of winding wire round the rods from a fixed point and binding the bars together at the connections and securely fixing the other end of the wire, whereby slipping becomes impossible. He has devised and describes in detail a simple and effective tool for winding the wire round the rods. Typical examples of the application of the principle to various forms of construction, such as plates of one, two or more series of network, square, round and polygonal columns, girder-work, arches, etc., are described and shown on scale drawings and photographs of the work at various stages of progress.

L. S. Z.

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[1] Proceedings American Society for Testing Materials, vol. 13, pp. 332–349.

Bending of Reinforced-Concrete Beams.

DR. MAX R. VON THULLIE.

(Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, Vienna, 1913, vol. 65, pp. 785–788.)

The Author first drew attention to the "third phase" in the phenomenon of the bending of reinforced-concrete beams in 1902,[1] and it has since been pointed out that although allowance had been made for variations in the coefficient of elasticity of concrete, no allowance was made for that of iron beyond the yield-point. The present article introduces this second variable in the "third phase" of the bending of beams. The variations in the elasticity of iron were obtained from standard automatic stress-strain diagrams, based on the experiments of Mehrtens.[2] A new formula embodying the above variables is worked out and applied to the experiments of Kleinlogel and Sanders. The formula is intended to give a method of intelligibility following the various phases of the bending of a reinforced-concrete beam up to its destruction.

C. J. G.

Stresses in Reinforced-Concrete Beams. W. CAIN.

(Proceedings of the American Society of Civil Engineers, New York, 1913, vol. 39, pp. 2067–2086.)

In the design of reinforced-concrete walls, it is often necessary to find the stresses in beams with top and bottom faces inclined to each other. As all the compressive stresses on a plane, normal to the top boundary-line, act at right angles to the plane or parallel to the face, and similarly the tensile stresses at the lower face would act parallel to that face, the stresses must change their direction from the top to the bottom face. The Author develops formulas to meet the case of beams with inclined faces of different kinds.

R. S. B.

Eccentrically-loaded Reinforced-Concrete Columns.

G. WEISSER.

(Technische Blätter, Prague, 1913, vol. 45, pp. 138–155.)

This is a mathematical paper establishing formulas for the calculation of reinforced-concrete columns, which are divided into two categories, one in which the load is applied inside the cross-section of the column, and the other outside. In both cases cubic equations are obtained of a somewhat complicated nature, but by omitting the compression in the armouring, considerable simplification is obtained, and the error is practically negligible, and in any case, on the right side. This statement is confirmed by means of four numerical examples, worked out fully both by the complete and by the approximate method.

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[1] *Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines*, 1902, No. 50.

[2] Mehrtens, "Statik und Festigkeitslehre" (second edition), p. 12.

H. R. S.

Spirally-reinforced Cast-Iron Columns on the Emperger System.[1]

(Beton und Eisen, Berlin, 1913, vol. 12, pp. 365–367.)

Further investigations into the results obtained by the reinforcement of cast-iron columns are discussed. These are the outcome of comprehensive tests conducted at the Technical High School in Vienna. These experiments were mainly directed to ascertain the resistance of such columns to bending, and have thus an important bearing on the loading capacity of slender columns of cast iron. Tables based on the results are given, and a graphic diagram shows the comparison between the bending points at various loads for columns of wrought iron, cast iron, reinforced concrete and reinforced cast iron. The methods of reinforcing the cast-iron columns are shown by photographs, and illustrations are given of the Ericson building at Vienna, where reinforced cast-iron columns are in actual use. A diagram indicates the relative sizes of columns of reinforced cast iron, spiral-wound concrete and reinforced concrete, each designed to carry a load of 265 tons. In the first case the 130 kilograms of cast iron need 13 kilograms of reinforcement, in the second case the reinforcement amounts to 172 kilograms, and in the third case the weight of wrought-iron reinforcement is 123 kilograms. The amount of concrete used for the three columns is in the proportion of 1 : 5 : 7, and the sectional areas are in the proportion of 1·3 : 5 : 7.

G. R. R.

Collapse Formula for Lattice-Girders and Columns.

Professor Fr. Engesser.

(Zeitschrift des Oesterreichischen Ingenieur- und Architekten-Vereines, Vienna, 1913, vol. 65, pp. 769–772.)

The formula proposed is deduced from that generally used for solid beams and columns:—$P = \frac{l^2}{8\,\delta}$; where P = force of collapse,

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[1] Minutes of Proceedings Inst. C.E., vol. clxxxix, p. 374, and vol. cxcii, p. 365.

l = length of beam, δ = deflection at centre. For lattice-girders this becomes:—$P_n = \frac{l^2}{8\,\delta_n}$; whence $P = P_n \frac{\delta_n}{\delta} = P_n\,a$. a, which $= \frac{\delta_n}{\delta}$, represents a factor by which the collapsing strength of solid beams differs from that of lattice-girders.

Several examples are given, and in one case where the girder consists of parallel top and bottom booms with diagonal struts and ties—$a = 1 : \left[1 + \frac{24\,d^3\,F_1}{l^2\,c\,f}\right]$; where $d^3 = 2\cdot 8\,h^3$ for slope of 45°, d = length of diagonal, c = vertical projection of diagonal, h = horizontal projection of diagonal, l = length of girder, F_1 = cross-section of one boom, f = cross-section of the diagonal.

Examples for columns are also worked out. The article is illustrated. C. J. G.

Observations on Bridge-Expansion. H. A. Loser.

(Engineering News, New York, 1913, vol. 70, pp. 1170–1171.)

Many engineers regard the recognized coefficient of expansion for a bar of steel as not applicable to a complex structure with joints. The Author made many experiments on the bridges of the New York, New Haven and Hertford Railroad, to determine the action of expansion bearings, and a detailed illustrated description is given of the apparatus used, by means of which forty-five observations were made on as many different structures of modern construction. Of these, sixteen were pin-connected trusses 182 to 217 feet in length, eleven were riveted-through trusses 70 to 145 feet, and eighteen were deck-plate girder bridges, 70 to 111 feet 6 inches long. The winter-temperatures were 15° to 56°, and the summer-temperatures 45° to 86° F. The variation from high to low temperature during a single range of observations was 18° change as a minimum to 84° change as a maximum. It was noted in this observation that the movement occurred at the rolling bearing for every 3° to 5° in temperature, and whenever such a movement occurred there was a loud noise. The bridge and its bearings were in good condition. The conclusion was that, even under ideal conditions of free movement, expansion does not take place smoothly and continuously. Hence great precision in temperature-readings is an unnecessary refinement. The noise accompanying successive expansion-movements suggests that there was an accumulation of expansion stress in the bridge prior to movement. A Table of results shows that they are in practical agreement as regards coefficients of expansion with that of a solid bar. Sixteen observations were made on pin-connected bridges, eleven on riveted connections, and eight on plate-girders. Some hints follow as to more effective settings of the rollers. C. O. B.

Proportioning of Long-Span Trusses and Cantilever-Bridges.

J. Mayer.

(Journal of the Franklin Institute, Philadelphia, vol. 176, pp. 645–670; vol. 177, pp. 35–64.)

Formulas, the outcome of 20 years' experience of the Author, are given, by which the weights of long-span bridges are related to the loads, the unit stresses and the general dimensions. Mathematical reasons and proofs are given in an appendix. Although complicated, the calculations of the weight of any long-span bridge can be effected in a few days, and it is easy to determine what the general dimensions and the shape of the trusses should be to obtain the minimum weight. A numerical example is given of an ordinary truss 700-foot span for a double-track railway. The number of panels and the depth of truss are obtained for minimum weight, both for carbon-steel, and partly carbon-steel and nickel-steel. In the former the total weight works out to 12,180,000 lbs., and in the latter there are approximately 2,200,000 lbs. of carbon-steel and 5,700,000 lbs. of nickel-steel. The second design is evidently the cheaper. The method provides for separating the weights of steel required for the various loads; hence, for example, the effect of a proposed change in weight of the floor can be seen. It is stated that the sum of all the secondary stresses seldom exceeds one-third of the primary stresses, but that unless special measures are taken the secondary stresses will be much increased on long-span cantilever-bridges. The causes of these secondary stresses and the measures to be taken to reduce them are given. H. R. S.

Weight and Cost of Bridges.

(Engineering Record, New York, 1913, vol. 68, p. 640–641.)

To eliminate level-crossings eighty-three overhead steel bridges were constructed in Buffalo with spans of 25 to 195 feet, and eighty-one of them 50 to 56 feet wide. The live-loading provided for consisted of a 15-ton steam road-roller, with 6 long tons on the forward axle and 9 long tons on the rear axle, 11 feet apart, with rollers 20 inches wide, spaced 2 feet 6 inches apart on centres on the former and 6 feet on the latter. In addition to the roller-load, clear portions of the roadways had to bear 100 lbs. per square foot, and the lateral systems were proportioned for a wind-pressure of 50 lbs. per square foot. The bridges were of many types of flooring, and the article is confined to comparison of these, which are described and illustrated, with weights and costs, and are criticized. These floors include buckle-plates and reinforced concrete with asphalt, wood and stone surfacing. C. O. B.

Reinforced-Concrete Road-Bridge with Suspended Decking.

C. Ritter.

(Beton und Eisen, Berlin, 1913, vol. 12, pp. 428–430.)

It became necessary to construct a bridge over the river Obra at Kosten in Posen, for a road-crossing, and the local conditions were such that either a flat-girder bridge or a bridge of the bowstring type in reinforced concrete must be erected. The depth of the river Obra at this point of crossing was 5 feet 3 inches at mean water-level, but the highest flood-level was over 7 feet above mean-water line, and the Government laid down that the bridge-opening must have a sectional area of 699·67 square feet. It was also imperative that the footways on either bank of the river should be maintained, and this excluded the choice of an arched bridge. It was found that, owing to difficulties of foundation, a bowstring bridge with suspended decking would cost less than a flat girder bridge, and it was therefore decided to erect the bridge with two arched supports, from which the roadway is slung. The bridge has a clear opening of 72·17 feet, and a width between the arched supports of 16·4 feet. The road rises on either side at 1 in 60 to the centre level section, which is 12·3 feet above mean water-level. The decking is formed of reinforced-concrete slabs 5·9 inches thick, with longitudinal and cross bearers. To avoid costly foundations and to resist the horizontal thrust of the concrete arches, tie-rods are carried across in beams at the road-level. These tie-rods are formed of three flat iron bars, inserted at each end into a common anchor-plate, 29·12 inches high by 17·31 inches wide. The mode of reinforcing the main arches with twenty-two iron bars, each 0·94 inch in diameter, is shown by diagrams, also the construction of the footways formed as cantilevers outside the main arches. The results of the tests of the bridge with two steam-ploughs, weighing 14 tons each, are set forth in detail. Photographs show the bridge in course of construction and the finished structure.

G. R. R.

Reinforced-Concrete Bridge at Odense, Denmark.

A. M. Poulsen.

(Teknisk Tidsskrift, Copenhagen, 1914, pp. 29-32.)

The bridge is on a skew of 25° and consists of three equal spans of bowstring-arches of a total length of 220 feet. A single pair of rails is carried between the arches, the clear distance between the latter being 15 feet 4 inches. The abutments are reinforced with vertical and horizontal rods at front and back, and are suitably strengthened where the rods for the arches are anchored. Each of the intermediate piers consists of two separate heavy columns in which are anchored the rods for the arches and which are connected at the top by a heavy girder. The bridge-floor consists of a continuous armoured plate and cross-girders at intervals of about 7 feet, and four longitudinals, two under the rails and two outside carrying the floor-plates and keeping the ballast in place. The bowstrings have a constant width of 30 inches and depths of 31½ inches at the centre to about 60 inches at the piers. The vertical hangers are 8 inches wide in the longitudinal direction of the bridge and 20 inches in the transverse; the reinforcement consists of a rod 1⅛ inch in diameter at each corner. The method of reinforcing, the dimensions of rods, mixtures of concrete, etc., are described in detail, and the Paper is illustrated by photographs.

L. S. Z.

Types of New York State Roads. W. G. Harger.

(Engineering News, New York, 1913, vol. 70. pp. 1148-1154; Engineering Record, New York, 1913, vol. 68, pp. 623-644.)

In the first article the official regulations, which came into force on the 23rd October, 1913, are quoted as to types, weights, dimensions, speed, etc., of allowed vehicles. Then follow classification of the State roads, and average cost per mile on one division for 1912 and 1913, for different types, for a width of 16 feet. There are main feeder-roads, main automobile-routes, secondary feeder-roads, cross roads, and pleasure roads or scenic routes. There is a general discussion on each of these, and other types, with much criticism, the conclusion being that the cost of a road system can be greatly reduced by the proper selection of the most suitable construction for each separate road. The width of pavement is regarded as an important factor, the Author believing that, provided the grading is kept the same as for a 16-foot road, in many cases the metalling can be reduced in width to 12 or 15 feet, using gravel or loose stone on the shoulders, which can be widened later if necessary.

In the second article the subject is dealt with as regards other types of roads in other States and countries.

C. O. B.

Tests of Concrete in Brick Pavements.

(Engineering Record, New York, 1913, vol. 68, pp. 450 and 457-458.)

The first article is an editorial comment on the second. In the second the determinator, a machine which had tested in a few days the effect of large mileage-wear on pavement of different kinds and on tires during the American Road Congress at Detroit, is described and illustrated. After giving details of the various road-surfaces distributed over the space on which the determinator was worked, the machine is shown to consist of a central vertical column or pivot, around which revolves a horizontal shaft, having heavy cast-iron wheels on each end. The wheels are 48 inches in diameter, with rims 3 inches wide. The weight transmitted to the floor by each wheel is 1,650 lbs. While the wheels remain at a constant distance apart, as they move round the central pivot the radius of the one increases and that of the other decreases, so that each wheel travels over a path 27 inches wide, and approximately 330 complete revolutions are required for a wheel to shift from the inside to the outside of the circular path. There is also a device imitating the action of horses' hoofs; 19,315 revolutions were made, and the condition they produced on the various pavements is shown by photographic reproductions. Tables of analyses are given.

C. O. B.

Biological Treatment of the Paris Sewage at Carrières-Triel.

LUCIEN FOURNIER.

(La Nature, Paris, 1913, Deuxième Semestre, pp. 439–443.)

An installation has been arranged for the biological treatment of such parts of the Paris sewage-water as cannot be employed for irrigation purposes before their discharge into the Seine, in connection with the works for regulating the sewage at Carrières-Triel. The general method of the working is explained by reference to a sketch plan and section. Reference is made to the experiments on sewage-treatment at Gennevilliers, which had led to the formation of biological tanks at Fond-de-Vaux. The results of these tests induced the authorities of the City of Paris to erect the works at Carrières-Triel on a mixed system, consisting of subsidence-tanks and artificial soil for filtration. The sewage-water dealt with here has already been partly purified at Clichy and at Colombes, and has been deprived of its heavier suspended matters, but it still retains its strong odour, which is very apparent in the first two septic tanks. The septic reservoir is constructed of concrete, and is divided into two compartments by a central division, with a total capacity of 176,500 cubic feet. The water from these tanks passes by suitable channels to a second series of depositing-tanks, situated below them. The contact-beds are in three compartments varying in area; the first has a surface of 2,120 square feet, the second of 3,195 square feet, and the third of 4,262 square feet, and the size of the filtering-material differs in each. The sewage-water is supplied either above the surface or from the bottom upwards, and the mode of working is explained by diagrams. The formation of the percolating-beds is shown in a section, and details are given of the surface-distribution of the sewage on the Laffly and on the Durey-Sohy systems. The percolating-beds have a total area of about 113,000 square feet, and are contained in ten sets of tanks each 229·6 feet long by 49·2 feet wide. Photographs explain the arrangement of the tanks and the method of working.

G. R. R.

Treves Sewage-Purification Works. T. SCHÜRMANN.

(Gesundheits-Ingenieur, Munich, 1913, vol. 36, pp. 789-792.)

The principal quarters of Treves, situated on the right bank of the Moselle, were sewered in 1900–1904 on the mixed system, and it became necessary to treat the sewage-water before its discharge into the river. Tank-treatment was at first adopted, but it gave rise to considerable difficulties, owing to the great bulk of the sludge, for which there was no sale. It was, therefore, proposed to abandon the use of tanks, and to subject the foul water to mechanical treatment. The volume of the sewage-water, as compared with that of the Moselle, is relatively very small. It amounts to the proportion of 1 : 666 at low-water level of the river, or 1 : 4,000 at mean-water level. The State authorities agreed to the proposed changes on the condition that all floating substances larger across than 0·118 inch were to be removed before the sewage entered the river. After lengthy trial it was decided to use the Windschild drum-sieve, a contrivance in the form of a truncated cone, fitted with perforated sheet-metal screens. The main feature of this apparatus is that the intercepted matters are removed from the sieves by compressed-air. Photographs and drawings explain the working of the machine. The drum is 14·43 feet in diameter, and the screens are 47·24 inches wide, with holes about $\frac{1}{10}$ inch in diameter. The drum is fixed at right angles to the sewer, and is driven by a 1-HP. electro-motor at a speed of 1 revolution in 3 minutes. Air, compressed to 2 atmospheres, is forced into an air-vessel by a 2½-HP. motor, while a water-spray for cleansing is supplied by a ½-HP. motor, and the water is pumped up from a well by a motor of similar power. It is stated that the circular perforations in the metal plates are better than the ordinary wire sieves for retaining the suspended matters. The sieves are cleaned by the air-blast, which clears away all the substances tending to clog the apertures, and this matter falls into the funnel opposite the centre of the drum. The sewage of 40,000 inhabitants produces, on the average 11-hour working day, 140 cubic feet of sludge. A Table indicates graphically the hourly amount of sludge collected day and night on certain working days in December, 1912. The total outlay on plant, including alteration to the outfall-sewer, was £1,800, and the working cost amounts to £187 per annum, deducting the value of the manure.

G. R. R.

Recent Improvement in Apparatus for Cleaning Filter-Beds.

OLLIVIER.

(Revue de Mécanique, Paris, 1913, vol. 33, pp. 459-473.)

Four types of apparatus are described and illustrated, the object of which is to remove mechanically the layer which forms on the surface of filter-beds. The principle of the design is as follows:—A suction-nozzle is carried by a traveller, and at the foot is fixed a horizontal knife, the edge of which can be regulated so as to skim off a top layer of the filter-bed 1 to 10 millimetres in thickness, the amount cut off depending on the rate of filtration and the impurities in the water. There are several channels in the suction-nozzle leading from its mouth to the suction-pipe, and they are so designed that the velocity of the water shall be equal at all points of the cutting edge of the knife. The water so sucked up contains mud resulting from the impurities and sand, and is discharged at the centre of a separator consisting of a double cone. It then rises between the two cones and falls over into a drain, carrying the mud with it. The sand, being heavier, is deposited at the bottom of the first cone, and is withdrawn at intervals. Calculations as to the power required, which amounts to about 4 kilowatts, and several sections and elevations and photographs of apparatus installed in different parts of France are given.

H. R. S.

Lead-Poisoning of Drinking-Water. Professor M. NEISSER.

(Gesundheits-Ingenieur, Munich, 1913, vol. 36, pp. 920-922.)

In the spring of 1913 a female patient of the city-hospital of Frankfurt-am-Main was treated for severe lead-poisoning. As no other reasons were apparent, it was surmised that the attack was caused by the presence of lead in the drinking-water, and the director of the hospital, Professor Schwenkenbecher, and the Author undertook an examination of the population of the village, in the vicinity of which the patient resided. A detailed account is given of the condition of the twenty-six inhabitants, twelve of whom were found to exhibit marked signs of lead-poisoning, six cases were suspicious, and only eight (all children) gave no indications of the presence of lead in the system. Concerning the water-supply, it was ascertained that the water was conveyed from the spring to the village in iron pipes, but that all the house-connections were lead pipes; the longest, which served the farm where the woman resided, was 590 feet in length. The means by which lead becomes dissolved are very complicated and are perhaps not yet clearly explained. Oxygen and carbonic acid are at times factors bringing about the solution of lead, but electrolytic action is likewise involved. The degree of hardness of the water due to carbonates is of great importance. The supply in the present instance was derived from two sources, the water of which was similar in quality. An analysis is given, and the presence of lead was detected in many cases, while the actual amount depended on the length of the house-connection. A short length of lead pipe long in use was found to be coated with a soft white substance containing about 96 per cent. of lead-carbonate. It is suggested that colloidal dissolved lead may be a factor in the injurious action, and some experiments bearing on this hypothesis are quoted.

G. R. R.

Water-Meter Performance in St. Louis. F. L. Bock.

(Journal of the Association of Engineering Societies, Boston, Mass., 1913, vol. 51, pp. 299–315.)

The various forms of water-meter which have been employed, and are used at present, are described. The earliest type was the plunger, followed by the disk and velocity types, which are now given preference over the more expensive rotary type. For sizes smaller than 3 inches the disk type is used, so called from the shape of its hard-rubber piston, and the disk mutates about a ball-and-socket joint bearing at its centre. From the tests it was found that near full velocity the impedance of the velocity type is much less than that of the disk type, which in turn is less than that of the rotary type. Experience in the work of the department showed that rotary meters lose their accuracy and sensitiveness gradually, and that the disk type maintains its accuracy better than the rotary. The velocity type maintains its accuracy very well. It is only used in the larger sizes (above 3 inches), and is the cheapest in first cost and maintenance. The Paper is illustrated.

R. S. B.

Completion of Los Angeles Aqueduct. W. W. Hurlbut.

(Engineering Record, New York, 1913, vol. 68, pp. 482–486.)

This aqueduct, 234 miles in length, from Long Valley, near the boundary of Nevada and California, to Los Angeles on the Pacific Ocean, largely through desert, was completed in November 1913. It comprises unlined canal, lined canal, covered conduit, tunnelling, siphons, by-pass, reservoir, and power-tunnels, covered conduit being the greatest length, about 98 miles, while there are about 93 miles of tunnelling, the cost being over £5,000,000. The waters provide for the City of Los Angeles, and the surplus will be available for irrigation and power. The sites of power-houses are being fixed. Some of the component parts of this great aqueduct have been described already[1]; others are fully described in the present article, with important details—for instance, analyses of the waters of the several sources of supply, the electric-power shovels, with cost of working, the Haiwee and other reservoirs, tunnelling, siphons, many items of total cost, wages, sale of power, etc. The article is illustrated and has numerous Tables.

C. O. B.

Design of Rolling Dams. A. G. Hillberg.

(Engineering Record, New York, 1913, vol. 68, pp. 654-657.)

The Author points out, that while the rolling dam is not entirely new, the first having been constructed in 1902, little information has been published, this being the chief reason for his treatment of the subject in a comprehensive manner. The main feature of such a dam is a water-tight steel cylinder, rolling on inclined rails, supported in lateral recesses in masonry piers or abutments. In its lower position it acts as a dam, and when opened, is suspended out of reach of floating matter. The manipulation is by a chain or wire-rope bound around one end. The uniform advance of both ends in raising or lowering is ensured by gearing, each end carrying a toothed rim engaging a rack fixed in the masonry. The advantages are:—Possibility of building discharge-openings of large spans and depths, absence of obstruction to debris when the dam is open, rapidity in operation, low resistance, great durability, small leakage and low maintenance costs. The operating machinery and the methods of securing tight seals are fully described. In figuring a rolling dam one of the fundamentals is that, in the closed position, the resultant force does not tend to roll it up the incline, and many instances of existing rolling dams are quoted in this connection. The subject is then treated mathematically, including the solution of problems of torsional stresses, the Author preferring the graphical to the analytical method, owing to its greater simplicity. Temperature-stresses are also dealt with. The article is illustrated, and a Table gives the main features of rolling dams in America and Europe.

C. O. B.

Jordan River Dam on Vancouver Island.

(Engineering Record, New York, 1914, vol. 69, pp. 62-64.)

This is a hollow reinforced-concrete dam, 136 feet in maximum height, 756 feet long, with a capacity of 612,000,000 cubic feet, of the deck-slab and buttress type. The article first describes the general scheme of hydro-electric power—the completed Bear Creek and Jordan dams, which, with two others proposed, will conserve 2,800,000,000 cubic feet. Then follow illustrated particulars of the main portion of the Jordan dam. The up-stream slope of the buttresses, which are 1 foot thick at the top and 3 feet 6 inches at the bottom, at 18 feet centres, is 1 to 1, and the down-stream slope 1 to 4, except for 18 feet at the top, which is vertical. The concrete in the decks, cut-off, beams and rollway was mixed in the proportion of 1 : 2 : 4. In the buttresses the mixture was 1 : 3 : 6, and the total quantity used in the dam was 21,185 cubic yards, for the reinforcement of which 380 tons of steel were used. Reinforced-concrete ties connect the buttresses at intervals. The design of the deck-slab is then described, as well as the flume, intake, foundations and the concrete moulds. The cost data show a total of £113,270.

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[1] Minutes of Proceedings Inst. C.E., vol. clxxvi, p. 343, and vol. clxxxiii, p. 423.

C. O. B.

New Big Bear Valley Dam—A Concrete Dam of the Multiple-Arch Type. J. S. Eastwood.

(Engineering News, New York, 1913, vol. 70, pp. 1284-1290.)

This is a reconstruction on a much more capacious and altogether different plan from the one replaced, and is of peculiar design. This multiple-arch dam is composed of a number of concrete buttresses supporting a water-resisting deck of concrete arches sprung between the buttresses. It has ten arches of 32 feet clear span, abutting on eleven buttresses. Its total length is 663 feet on the crest, and its maximum height from crest to base is 92 feet. The water-face of the structure and the rear edge of the buttresses are given such slopes as to bring the resultant of the water-pressure load and that of the structure through the centre of the base of the buttresses at the highest portions. The slope of the water-face, up to within 24 feet at the top, is 36° 52′ from the vertical, and from that point to the crest, vertical. The slope of the down-stream edges of the buttresses is two vertical to one horizontal throughout, the vertical top of the arches giving them a top width of 10 feet from the spring line to the back edge. The arc of the extrados of the arches is 140° 8′, with radius 17 feet, these being constant, while these features of the intrados vary. Strut-tie members are provided between the buttresses to take lateral stresses which might be set up by earthquake disturbances or other vibrations. These strut-ties consist of a combination of T-beam and a supporting arch all tied together by heavy steel reinforcement. The principle of the multiple-arch design is explained to be an amplification of that of the arch, in which advantage is taken of the water-pressure to assist the weight of the structure to get the required stability. There are no other than compressive stresses in the multiple-arch dam, when the loading is moderate in amount, except that due to the bending owing to rib-shortening at the spring lines of the extrados and at the crown line of the intrados. These are insignificant. There are several illustrations.

C. O. B.

Rock-Grouting and Caisson-Sinking for the Hales Bar Dam.

(Engineering News, New York, 1913, vol. 70, pp. 949-956 and 1038—1039.)

The first article describes the interesting foundation work for the dam where fissures in the rock-foundation strata called for the use of special methods, such as cement-grout injection on a large scale and pneumatic caissons sunk through the worst fissures to prevent water-flow. Three contractors successively grappled with the difficulties of the work, and finally the engineer to the company constructing the dam had to complete it. The design of the dam, which is of cyclopean concrete of gravity section, much modified during the progress of the work, is described. Then follow details of the difficulties encountered, necessitating these modifications. The method of rock-grouting used at the east end had to be abandoned at the west end, and supplanted by the compressed-air caisson method. The foundations of the power-house are also described, the caissons throughout being of reinforced concrete. The article is in great detail and well illustrated. The second article, after drawing attention to the unusual character of the works, blames the Government of the United States for delay in allowing certain modifications, leading to great additional expense, and deals with the financial aspects in view of the general difficulties which were encountered.

C. O. B.

Storage to be provided in Impounding-Reservoirs for Municipal Water-Supply. ALLEN HAZEN.

(Proceedings of the American Society of Civil Engineers, New York, 1913, vol. 39, pp. 1943-2044.)

The Author endeavours to ascertain the relation between the storage provided in an impounding-reservoir on any stream and the quantity of water which can be supplied continuously by it. The records of flow of many rivers were taken, tabulated and plotted. Smooth curves were drawn to show the most probable curve, and the paper used was ruled with lines spaced in accordance with a probability-curve, or, as it is otherwise called, the normal law of error. The spacing of the lines was computed from probability-curve tables, and arranged so that the line which represents the summation of the probability-curve, when plotted on it, is straight. Thus if the data for any series correspond strictly with the law of error, the points will lie on a straight line. This was found to be nearly so for the observations. This method enables estimates of flow to be made for any watercourse similarly situated to that on which these figures are based. Numerous diagrams show the results of the observations.

R. S. B.

Reinforced-Concrete Reservoir and Coagulation-Plant at St. Louis, Mo. E. Flad.

(Proceedings of the American Society of Civil Engineers, New York, 1913, vol. 39, pp. 2133-2141.)

The Auheuser-Busch Brewery takes from the Mississippi River some 5,000,000 gallons per day through two 20-inch pipes. The water is siphoned into one of two intake-wells, from which it is pumped into settling-tanks. It flows by gravity through the settling-tanks, thence through the filters, and is then pumped into the distribution system. The three centrifugal low-service pumps are in a brick pit 33 feet in diameter and 40 feet deep. There are two steel settling-tanks 75 feet in diameter and 28 feet high, one circular concrete reservoir 150 feet in diameter and 30 feet deep, and one rectangular covered reservoir of 830,000 gallons capacity. The filter-plant comprises six circular Jewell filters 16 feet in diameter, and three Reisert filters 34 by 15 feet. The water is settled by adding sulphate of aluminium and lime. The reinforced-concrete reservoir has vertical sides, and is 153 feet 6 inches in diameter and 35 feet deep. There is a 4-inch reinforced-concrete wall with buttresses, which crosses diametrically, leaving 14 feet opening on one end. The foundation is a 12-inch layer of concrete reinforced in two directions, and on the top of this lies the bottom of the reservoir, which is 6 inches thick, and reinforced in a similar manner. The side walls are 7 feet 6 inches at the base and 1 foot at the top. There are three lines of 1¼-inch-round bars at the bottom, and two lines of ¾-inch-round bars at the top. The bottom slopes towards the centre to allow for cleaning. The total cost of the reservoir, including pipes and accessories, was approximately £10,700.

R. S. B.

Reinforced-Concrete Standpipe with Sliding Base. W. Mueser.

(Engineering Record, New York, 1914, vol. 69, pp. 43-44.)

The inside diameter is 40 feet, with a height of 100 feet from bottom to overflow. It is of a new type, discarding the old practice of firmly connecting the circular wall with the bottom. This is not only disconnected from the bottom by a distinct joint, but by means of anti-friction materials in the construction of the joint the expansion and contraction of the circular wall under changing water-pressures is facilitated, and an elastic asphalt seal, which adjusts itself to these changes, waterproofs the wall against the bottom. At the joint of this standpipe, which is at Fulton, New York, the concrete base is trowelled to a smooth finish, then plastered with a ⅛-inch coating of graphite paste, and covered by a 20-gauge copper sheet, on which the wall rests. Possible leakage through the joint is prevented by a trapezoidal asphalt wedge on the inside of the wall. The wall is 18 inches thick throughout, and reinforced with rings of diamond reinforcement-bars, the rings being in two vertical planes to facilitate erection and distribution. Reinforcing struts, described in detail, are also used. The tank is surmounted by a reinforced-concrete dome and a lantern. Particulars of the reinforced concrete are given, as well as the methods of construction. Continuous concreting was used in the walls, so as to get a monolithic structure without horizontal seams, the work being done in three shifts. Erection of steel rings and concreting proceeded simultaneously day and night. There are several illustrations.

C. O. B.

Works for the Regulation of the Elbe. STECHER.

(Zeitschrift für Bauwesen, Berlin, 1913, vol. 63, pp. 631-636.)

Reference is made to the gradual silting-up of the navigable channel of the Elbe and to the works begun in 1864 to effect an improvement in the vicinity of Söbringen and Pillnitz, a stretch of about 3,400 yards. The first attempts at regulation were in the form of pitched embankments or groynes (parallel works), constructed 123 yards apart, with a view of confining the central parts of the stream within the narrowest channel. The irregularities in the bed of the river were dredged away to maintain a sufficient width for navigation purposes. At the Pillnitz Island, the deeper (right) arm of the river served for the passage of the boats, and the shallower (left) arm has by degrees become dried up at low water. The works undertaken to narrow the main channel served their purpose at mean-water level, but at low-water the river wound about in an irregular course over the wide bed. Various impediments to navigation arising from this cause are discussed, while the tonnage of the craft using the river had to be diminished. A Table is given to show the great increase in tonnage on the Elbe, and it was finally decided in October, 1908, to carry out the regulation works herein described, so as to secure a deeper channel to utilize the main stream in times of low-water, with a fairly uniform fall and in a more direct course. The various recent changes in the level of the Elbe are discussed, and the position of the new channel, which is kept as far as possible in the middle of the river-bed, is defined. The works were in the nature of parallel groynes of hard material with intermediate filling, the embanking and prolonging of the Pillnitz island and dredging operations. In the course of dredging, masses of stone, nearly 2 cubic yards in bulk, were encountered, and special contrivances had to be rigged up on staging built between two barges, with iron hoisting-apparatus to raise them from the river-bed. Illustrations are given of the mode of working and of the plant. The cost so far has amounted to £14,250.

G. R. R.

Cross-Section of Canals. E. DOUCET.

(La Technique Moderne, Paris, 1913, vol. 7, pp. 422–425.)

The Author contends that the ordinary method of laying-out the cross-section of canals is incorrect and leads to unnecessary dredging. He first determines the true cross-section of equilibrium which will eventually establish itself, supposing that there is no silting-up, based on the principle that this section will be such as to oppose the minimum resistance to the flow of the water in the canal. He thus determines the equation to the curve of the final profile. As a verification he compares this equation with careful measurements taken in the case of three canals, and finds that the differences are within the errors of measurement. He further deduces a graphical method for determining the cross-section to which the canal should be cut in order to obtain eventually the true section.

H. R. S.

Berlin-Stettin Ship-Canal.[1] MIEHLKE.

(Deutsche Bauzeitung, Berlin, 1913, vol. 47, pp. 789–847.)

By the construction of the Berlin–Stettin ship-canal, the latter port will be enabled to compete with Hamburg, which, since the completion of the Kaiser Wilhelm canal, has been better situated for eastern commerce. The Oder–Spree canal and the Elbe–Trave canal have also favoured Hamburg. In spite of the fact that Stettin had spent £900,000 in the improvement of her harbour and shipyards she was unable to compete effectively with Hamburg. The Prussian Government therefore decided to construct a ship-canal to take the place of existing canals, having a total length of 120 miles, with twenty locks. The new canal begins at the Plötzensee, at Berlin, and has locks large enough for vessels of 600 tons. By means of a map the Author describes the route in detail. One of the chief improvements is the use of only three locks in the place of eighteen on the old Finow canal. The present cross-section is everywhere sufficient to permit two vessels, each 214 feet long by 26·2 feet wide, with a draught of 5·75 feet and burden of 600 tons, to pass each other easily; but in future it will be possible to increase the depth, so as to permit of the passage of three such vessels. Cross-sections of the canal are given at several different points, and the principal structures are described and illustrated. The canal is carried by a reinforced-concrete bridge over the Berlin–Stettin railway, and there is an important bridge with regulating sluices at Eberswald. The estimated cost of the canal was £2,175,000, and although the works are not yet entirely finished, it is believed that this will not be exceeded.

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[1] Minutes of Proceedings Inst. C.E., vol. cxcv, p. 416, and following Abstract.

E. R. D.

Auxiliary Machinery for the Berlin–Stettin Canal.

MAX BUCHHOLZ.

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1913, vol. 57, pp. 1809–1820; 1914, vol. 58, pp. 88–95, 130–143.)

This is a continuation of the article giving details of the construction of the Berlin–Stettin Canal,[1] and describes with the aid of 111 figures the sluice-doors at Plötzensee, Spandau and Leibnitz, the roller lock-doors at the East-Oder, and also the electric equipment for operating the latter. The large sluice-valves controlling the storage-reservoir at Niederfinow, the electric haulage-locomotive used for the flight of locks at this latter part of the canal, and finally the emergency- and safety-doors and weirs required in connection with the canalization of parts of the Oder, are also described.

C. J. G.

Widening of the Kaiser Wilhelm Canal. F. EISELEN.

(Deutsche Bauzeitung, Berlin, 1913, vol. 47, pp. 861–935.)

In 1907 the German Government authorized an expenditure of £11,150,000 on a very comprehensive scheme for the widening of the Kaiser Wilhelm canal. This canal, begun in 1887 and completed in 1895, connects the harbour of Brunsbüttel, at the mouth of the Elbe on the North Sea, with Holtenau on the Kiel estuary in the Baltic Sea. The total length of the canal is about 61 miles, and its cost was £7,800,000, of which about £550,000 represented the value of the land purchased. The actual widening works were begun in 1909, and have made such good progress, without, however, stopping the ordinary traffic, that it is hoped during 1914 to open the new portions for service. Mr. H. W. Schultz, the head of the works department at Kiel, has furnished the Author with full details of the construction. When the canal was originally designed it was thought sufficient to provide for the passage of a single line of vessels not exceeding 475 feet in length, 75·5 feet in beam, and 28·0 feet in draught. The width of the bottom was therefore made 72 feet and the depth of water 29·5 feet, with a width of 220 feet at the water-surface and a cross-sectional area of 4,500 square feet. Eight passing-places were provided. Traffic has increased from 19,600 ships with 1,848,458 tonnage in 1896, to 52,817 ships with 8,478,261 tonnage in 1911. When the present works are completed the canal will be 144 feet wide at the bottom, with a depth of 36 feet, and a width of 335 feet at the surface of the water, and a cross-sectional area of 8,900 square feet, about double the former area. New high-level bridges have been built, of which the finest is that for the railway at Rendsburg. The article is illustrated.

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[1] Minutes of Proceedings Inst. C.E., vol. cxcv, p. 416, and preceding Abstract.

E. R. D.

Mississippi Lock at Keokuk.

(Engineering News, New York, 1913, vol. 70, pp. 964-972.)

The great Keokuk dam had to be provided with a lock to prevent interruption to navigation. It is notable for its size, 400 by 100 feet, its single maximum lift of 40 feet, and its gates, the lower of which are of the Mitre type, similar to those at Panama, while the upper gates are of a floating type not before used, and are raised and sunk by compressed-air and gravity respectively. The requirements of the United States Government necessitated the provision of a dry dock and repair-shops, which are described. There is also a power-installation. The great dam[1] is 4,650 feet long, with a spillway length of 4,278 feet. The lock-walls are of concrete, standing on a solid rock floor. The floating lock-gates, of which one is used for the dry-dock entrance, are the most remarkable features of the work. They consist of trussed-steel tanks, moving in vertical slides, and sinking below the level of the sill. To close the lock, air is admitted to an open bottom chamber in the gate, to blow out the water and cause the gate to rise. To open the lock, the air is allowed to escape, and the weight of the gate sinks it to its lower position. Details of this mechanism are given at great length. The lower-end gates, which are of steel, and the power-plant and operating machinery are fully described. All operations are controlled from a concrete building placed on the upper wall of the lock, indicators showing positions of valves, gates, etc. There are many illustrations.

C. O. B.

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[1] See *Engineering News*, 28 September, 1911.

Reinforced-Concrete Lighthouse at Alexandria.

Dr.-Tech. W. Stross.

(Beton und Eisen, Berlin, 1913, vol. 12, pp. 309-312.)

During 1911 the lighting-buoy at the entrance of the harbour of Alexandria was destroyed by a great storm, and it became necessary to replace it with all possible speed. It was decided to erect a reinforced-concrete tower which took the form of a base, carried out as a caisson, for the foundation, with a shaft to support the lantern. The lower part was constructed on shore on a slipway, and was launched into the harbour when the walls were only partly completed. It sank to a depth of 9·84 feet, and was moored to the sea-wall to build up the sides to the full height. The total height of the caisson was 45·93 feet, and the outside dimensions were 31·16 feet by 27·88 feet. The plan was seven-sided, and consisted of a half-octagon with a parallelogram at the back. The flat base was extended to obtain a better support, and was 41·0 feet in length by 37·72 feet in width, with a thickness of 7·87 inches. The bottom was attached to the walls of the caisson by eighteen consoles, also 7·87 inches thick, and the caisson itself was constructed of concrete 5·9 inches thick with round-bar iron reinforcement. A diagram shows the cross-bracing employed to stiffen the structure, and full details are given of the nature of the reinforcement. The special shape was chosen to break the force of the waves. The light-tower, also formed of concrete, and octagonal in plan, was fixed above the caisson, and had a total height of 35·75 feet. It was anchored to the base by the circular iron reinforcing-bars. When the structure was finished it was supported by two barges and towed towards its final position, but the tow-rope being attached to the shaft, the tower was torn from its base, and the caisson and superstructure had to be taken back into the harbour, where the tower was reconstructed. Ultimately the work was completed and the lighthouse was sunk to rest on the sea-bottom, in the place assigned to it, by filling the caisson with concrete. Some months later the Austrian-Lloyd steamer *Amphitrite* collided with the fabric, causing serious damage, and giving the caisson a severe list. It is intended to repair the injury by passing down concrete through the water. Photographs illustrate the various stages of the work.

G. R. R.

Improvements at the Port of Nantes. Charles Aubert.

(Le Génie Civil, Paris, 1913, vol. 64, pp. 81-87.)

Nantes, at one time the chief port of France, is some 35 miles from the sea, and consequently has lost its place through the advent of the deep-draughted vessel. Recently, however, great stimulus has been given to its trade by the opening out of the Normandy iron-fields, the port during 1912 handling some 180,000 tons from this source alone. Since 1900 the deepening of the approach has been actively pushed forward, and now the principal drawback is the inadequacy of quay-accommodation. The Loire at Nantes is encumbered by several islands, and the old quays lie on the mainland of the northern arm. These quays, insufficiently wide at the outset, were further hampered by the railway to Brest, and widening, which was economically impracticable on the land-side owing to the precipitous banks, has recently been effected to the extent of 47 feet by projecting jetty-work into the river. Notwithstanding this widening the accommodation was still entirely insufficient, and an additional length of quay, amounting to 5,546 feet with a width of 262 feet, has now been partly completed on the southern side of the main island, which already possesses railway-communication with the shore. The new quays fall within two distinct types. Where the rock is found at a low level 20-inch octagonal piles of reinforced concrete are first driven, their heads being cut off at about half-tide level, where they are embedded in a mass of concrete deposited in a reinforced-concrete box, on which the quay-wall is subsequently erected. Where the rock lies at a high level the quay takes the form of an arched viaduct supported on piers 49 feet centre to centre, the arch crowns being covered with 6·5 feet of filling to form the quay. I. C. B.

Coal-Piers on the Atlantic Seaboard. J. E. GREINER.

(Proceedings of the American Society of Civil Engineers, New York, 1913, vol. 39, pp. 1771-1819.)

There are four harbours of importance between Maine and Florida where coal is discharged directly from commercial coal-piers into vessels—New York, Philadelphia, Baltimore and Norfolk—and the Author investigated their facilities for coal-handling. The coal-piers may be divided into three general classes:—(1) Gravity plants, (2) Mechanical plants, and (3) Combination plants; and the different kinds of appliances under each of these headings are discussed. There are fifty gravity plants at the four ports, seven mechanical plants, and three combination plants; thus the gravity plants far outnumber the others. The construction of most gravity piers is of a temporary character, and consists of pile foundations and framed timber superstructure. After discussing the costs of operation, the results are summed up with recommendations as to the best proportions for piers and coal-plant in view of existing traffic and dimensions of vessels. The Paper is illustrated by drawings of the various appliances with which the piers are provided. R. S. B.

New Laboratory of the Automobile Club of France. G. LUMET.

(La Technique Moderne, Paris, 1914, vol. 8, pp. 5–8.)

The new laboratory recently opened by the Automobile Club at Neuilly-sur-Marne contains all the apparatus required for testing oil- and petrol-engines, the thrust of screws, the calorific values of fuel-oils, and the coefficient of friction of lubricating oils. A number of test-plates are arranged provided with connections for cooling water-supply, electric leads for ignition, and means for getting rid of the exhaust. The power is absorbed either by calibrated fans or by dynamo-dynamometers. In the latter case autograph records can be taken of the speed and of the brake-horse-power. To determine the calorific value of a fuel-oil a single-cylinder horizontal engine has been provided, the power being absorbed by means of a calibrated dynamo, the load being a bank of glow lamps. The exhaust is cooled by a water-jacket, so as to determine the heat-loss in it. The heat lost in the jacket of the engine is also measured, and by making allowance for radiation, the total heat produced by the oil is obtained, and thus its calorific value when working in an engine is measured.

H. R. S.

Dynamo Electric Lighting for Motor-Cars. A. E. WALLER.

Advantages of Clutch-Type Generator and Separate Starting and Lighting Units for Motor-Cars. A. CHURCHYARD.

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 31, pp. 1971–1985 and 1987–1993.)

It is stated in the first Paper that, based on numerous experiments, it was found that the most satisfactory arrangement for headlights consisted of two 21-candle-power 6-volt tungsten lamps placed in a 10-inch parabolic reflector, 5½ inches deep. Side lights should be 4 candle-power, and the rear lights 2 candle-power. The dynamo requires to be capable of furnishing 10 amperes, and in order to regulate the voltage, and also to give current when the car is standing still, a three-cell lead battery must be provided. Automatic control of the system should be adopted, and various methods of doing this are described. The suitable types of dynamos are discussed, and the speeds at which they should run. A geared dynamo running at 1,000 revolutions per minute, and driven at approximately twice the engine-speed is recommended as being on the whole most advantageous. Exhaustive experiments have shown that a battery having 160 square inches of positive and 100 square inches of negative plate surface is satisfactory. Such a battery under ordinary working conditions will not be overheated. In the second Paper it is argued that the dynamo for lighting should run at constant speed, for the following reasons, amongst others:— In charging a battery there is a large current when the battery is low, and this tapers off to a smaller charge as the battery gets full. It can run the lights even if the battery is disconnected. The efficiency, notwithstanding the slipping of the clutch, is higher than that of a machine regulated in connection with change of speed. Although the dynamo can be designed so as to act as a starting motor, using current from the cells, it is recommended that the motor for starting be a separate unit, because the dynamo should be shunt-wound and the motor series-wound.

H. R. S.

Electric Equipment of Gasolene-Automobiles. F. CONRAD.

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 1995-2005.)

The use of the lighting dynamo for providing current for ignition is considered in detail, the high voltage for the spark being obtained by means of an induction-coil. The dynamo-supply being at constant voltage at low speeds of the car, the primary current will be built-up to a value dependent on the resistance in the circuit, whilst at higher speeds of the car there may not be time to build-up sufficient current. A device has therefore been designed to limit the current at the lower speeds. It consists of two centrifugal operating cams, which change their position with the speed so that the contact is held closed for an approximately constant time. A sectional view of this device is given. For starting the car a small motor is provided, and torque-curves are given for four-cylinder and six-cylinder engines. In the former great variation is shown, and when the engine is hot there is a slight negative torque. In both cases the torque when the engine is cold is nearly twice as great as when it is hot.

A photograph is given of the complete outfit, showing geared dynamo and ignition-device.

H. R. S.

Charts for Journal-Bearings. A. K. PEDERSEN.

(American Machinist, New York, 1914, vol. 39, pp. 1017-1022, 1069-1076.)

In a previous article[1] bearings lubricated by means of a perfect oil-film were considered. This article is a continuation, and also deals with bearings having a semi-perfect oil-film and lubricated by means of oil-pads or oil-cups. Formulas are given to determine the stresses, although, as a rule, the dimensions of bearings are not determined by these. There are also formulas for determining the deflection. The working limit for pressure with a perfect oil-film is stated to be $58{\cdot}7\sqrt[3]{v}$. Formulas are derived for determining the dimensions of bearings, and an alignment-chart is given resulting from these formulas. Formulas are also furnished for cases when the maximum pressure has to be allowed, giving the minimum dimensions of bearings, and another chart is prepared from them. The friction of any particular bearing depends partly on true surface friction and partly on the shearing of an oil-film, and Tables are given to determine the total amount in various types of bearings. The temperature attained by bearings is determined, and therefrom the horse-power lost, and two charts are given, by means of which these figures can be obtained in any particular case; thus there are scales for the revolutions per minute of the shaft, the total load on the bearing, the diameter of the journal, the ratio of length to diameter, and from these data the temperature of the bearing and the horse-power lost can be obtained by drawing transversals on the chart.

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[1] *American Machinist*, vol. 37, p. 599.

H. R. S.

Record of Pressed Fits. C. F. MacGill.

(Journal of the American Society of Mechanical Engineers, New York, 1913, vol. 35, pp. 1657–1667.)

This is a record of the allowance made on 206 force-fits, supervised by the Author. The shaft-diameter was 3½ to 20 inches, and the material of the hub was sometimes cast-iron and sometimes steel. The Author's experience is that it is not necessary to increase the allowance in proportion to the shaft-diameter, but that 0·002 to 0·004 inch for steel hubs and 0·003 to 0·005 inch for cast-iron hubs invariably give good results. He is of opinion that an allowance greater than 0·006 inch for cast-iron hubs serves no useful purpose. Formulas are given, by means of which the maximum tension in the hub, the radial pressure and the coefficient of friction can be obtained. These figures are given in a tabular form for the 206 force-fits referred to above, together with the pressure in tons required to push the shaft in. The pressure varies from about 20 tons to 160 tons, and the radial pressure from 550 lbs. up to a little over 10,000 lbs. per square inch. The average coefficient of friction is about 0·2, and it varies between 0·1 and 0·36.

H. R. S.

Critical Speed of High-Speed Shafting. Dr. VICTOR BLAESS.

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1914, vol. 58, pp. 183-189.)

A graphical method is given to investigate the behaviour of high-speed loaded shafting, and stress is laid on the stable character of the motion, and consequently of the resulting forces. The method described is checked against a mathematically-designed shaft, the behaviour of which at a high speed is known; it is shown that the new method forms a valuable check on the more tedious mathematical determination. The Author finally compares the results obtained by his method with Dunkerley's empirical formula, and at the same time deduces a scientific explanation of the latter's formula. The article is illustrated.

C. J. G.

Forty-Foot Boring- and Turning-Mill. E. A. SUVERKROP.

(American Machinist, New York, 1913, vol. 39, pp. 719-723.)

The table of this machine has two bearings, one 18 feet 4 inches in diameter and 10 inches wide, and the other about 6 feet in diameter and 6 inches wide. The spindle runs in a white metal bush placed in a cast-iron housing, but there is no step bearing. There are means of adjusting the spindle. The machine weighs about 285 (short) tons, and three changes of gear are provided. There are several photographs, including the motor-drive, the foundations, the machine erected, and examples of work done, such as a large dynamo-spider, 33 feet inside diameter. The horizontal slide of the machine was cast in two parts and bolted together at the centre. Over it is placed a cast-iron girder, to which it is connected by a number of screw-bolts to provide for accurate adjustment. This adjustment was effected by means of a fine piano-wire, tightly stretched horizontally together with a height-gauge fitted with an electric contact. A difference of 0·0001 inch could be measured. The power required without cutting is 4½ to 5 HP. increasing to about 15 HP. when cutting, with two tools at 15-foot radius.

H. R. S.

Study of the Properties of Tool-Steel. Captain P. DENNIS.

(Revue d'Artillerie, Paris, 1913, vol. 82, pp. 377-397; vol. 83, pp. 36-66 and 127-182.)

This study is divided into two parts. In the first the law relating to the speed of cut with temperature of cutting-edge, both for carbon and for high-speed tool-steels, is established by means of the Herbert testing-machine, and it is found that the output depends almost entirely on this temperature, whether it be attained by feed speed or depth of cut, or the application of lubrication. Hence the results obtained from this machine, when plotted, give curves of "output-temperature," and they show two points of maximum output and one point of minimum output. In the case of a high-speed chrome-tungsten steel quenched from 1,300° C. in a lead bath at 600° C., the first maximum of output occurs at the temperature of 215° C. of the cutting-edge. The minimum is at 255° C., the second maximum at 290° C., and when the cutting-edge is at 340° C. the output is nil.

In the second part this law is applied to practical cases, and in the first instance a standard cut of 0·5 millimetre feed and 5 millimetres depth is taken, and the speed of cut for the tool-steel referred to above necessary to obtain the quoted temperatures is given for various steels and bronzes. The following are some of the figures given:—

	Temperature of Cutting-Edge.	Corresponding Speeds in Metres per Minute.				
		Mild Steel.	Medium Steel.	Very Hard Steel.	Grey Cast Iron.	Phosphor-Bronze.
	°C.					
First maximum output	215	26	20	6	33	60
Minimum output. .	255	35	25	8	42	77
Second maximum output	290	41	29	9	52	95
No output . . .	340	52	37	11	65	110

It is then explained how allowance can be made for other feeds and depth of cut, and the question is investigated how to obtain, in various cases, the most economical speed and cut, allowing for tool-renewals. Finally, by considering the price of tool-steel, rules are given for determining the type of tool-steel to purchase according to circumstances. Plates show characteristic curves of various tool-steels, and diagrams of cutting speeds with the various materials are given. Two of the main conclusions arrived at are as follows:—The output of a tool-steel is constant when the speed of cut varies inversely as the cube-root of the product of the square of the feed by the depth of cut. If a piece of work can be completed without grinding the tool, the speed of cut corresponding to the maximum output should be adopted, but if the tool has to be re-ground, then, in order to do the work in the minimum of time, the speed of cut should exceed that corresponding to the maximum output.

H. R. S.

Continuous Manufacture by placing Machines in Accordance with Sequence of Operations. O. C. BORNHOLT.

(Journal of the American Society of Mechanical Engineers, New York, 1913, vol. 35, pp. 1671–1678.)

The cost of moving work in progress from one tool to another is considerable, and great saving can, therefore, be effected by laying out the machines in accordance with the sequence of operations, as compared with grouping the same class of tools together. To prove and illustrate this statement the Author gives two examples—the manufacture of a universal knuckle-joint and the boring of cylinders for petrol-engines. As regards the latter, a plan of the arrangement of the tools is given, and it is shown that to handle 100 cylinders per hour would require twenty-four men. Incidentally less raw stock has to be kept when the machines are placed in sequence than when they are grouped.

H. R. S.

Empirical Design of Gas-Engines.

G. W. LEWIS and A. G. KESSLER.

(American Machinist, New York, 1913, vol. 39, pp. 601–605.)

Empirical formulas for calculating the leading dimensions of gas-engines have been obtained by plotting the actual dimensions of over 100 different sizes of engines built for various manufacturers. For example, the brake-horse-power is a function of the product of $D^2 L N$, and it is shown by plotting that this function is, for all practical purposes, a straight line, varying as to whether the engine is using gasolene, producer-gas, or natural gas For producer-gas the formula is $\text{B.HP.} = \frac{D^2 L N}{15{,}400} - 0 \cdot 7$. In a similar way the relations are obtained between revolutions per minute and brake-horse-power, and between the stroke and the diameter of cylinder. For producer-gas-engines these formulas are: Revolutions per minute $= \frac{855}{\sqrt{\text{B.HP}}} + 130$, and $L = (1 \cdot 55\, D - 1)$ inches. These results are combined in single diagrams according to the type of engine and the kind of gas used, and from these diagrams the leading dimensions of a gas-engine can be rapidly obtained for any given gas. The use of these graphs is illustrated by numerical examples; they are compared with Guldner's formulas, and a good agreement is shown.

H. R. S.

Increasing the Output of Otto-Cycle Gas-Engines.

W. **Hellmann.**

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1914, vol. 58, pp. 105–108.)

The Author shows that the output of gas-engines may be increased by 25 per cent. by the judicious application of scavenging air under pressure. The blower required absorbs about 2½ per cent. of the power of the engine, but, contrary to usual experience, the exhaust-pressure is not affected in any way by the increased output. The admission-valve is arranged to take an air-piston, and special air-channels are provided, whereby the quantity of scavenging air and also the quality of the mixture can be varied at will. Experiments were made to determine the increase in output of existing gas-engines, special attention being paid to accessibility and any tendency on the part of the valves to jam after long periods of rest. The machines gave satisfaction both from a thermal and mechanical point of view. The admission and regulation of mixture for gases of different calorific values are also dealt with. The article is illustrated.

C. J. G.

Missong Single-Cylinder Compound-Engine.

Professor **Pfleiderer.**

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1913, vol. 57, pp. 2030–2036.)

In order to increase the economy of steam-engines the exhaust-steam is often used for heating purposes, and in due course the steam is supplied to the heating-systems at an intermediate pressure and then returned to a second cylinder, the piston of which works between atmospheric and condenser pressure. The economy of this system has often been questioned on the ground that the cost of the condensing-plant is not covered by the economy effected. This induced Mr. J. Missong to design an engine in which the steam is exhausted at an intermediate pressure, passed through the heating-apparatus, and returned to the opposite end of the same cylinder. The engine thus becomes a single-cylinder compound-machine. Diagrams and Tables indicate the economy obtainable, and, owing to the balance of pressure being always on one side of the piston, the engine runs noiselessly and shows very little wear in the moving parts. The amount of steam admitted to the low-pressure and high-pressure side is regulated by an automatic pressure-valve working in conjunction with a drum-type governor. The quantity of steam supplied to the heating-apparatus thus automatically controls the steam-supply to the engine. The article is illustrated.

C. J. G.

Cooling of Steam below its Saturation-Point. A. STODOLA.

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1913, vol. 57, pp. 1739–1748, 1776–1783, 1820–1826, 1860–1864.)

It has been shown that surprisingly little condensation takes place in a jet of saturated steam until a certain critical pressure is reached. This phenomenon is of importance in turbine design, and being but little understood the Author carried out experiments to arrive at some satisfactory explanation, with the following results:—(1) Condensation of supersaturated steam takes place when the supersaturation-coefficient lies between 3·4 and 4, and takes place in about 2×10^{-5} of a second. The steam, therefore, leaves the nozzle in either a saturated or a very slightly supersaturated condition. (2) Retardation of condensation is not due to the absence of small particles of dust (centres of condensation), as a repetition of Hirn and Carin's experiments showed that such condensation-centres are present in ordinary steam. (3) Supersaturation or cooling of the steam below its saturation-point is not due to the short expansion-period, i.e., to insufficient time for the molecules to form into drops. It is caused by the bombardment of molecules against a drop of water, which results in an extraordinarily active exchange of molecular and heat energy, such that with even the most rapid rate of expansion the actual temperature differs but slightly from the critical temperature determined by the existing capillary surface tension. (4) It is further shown from the entropy diagram that if the supersaturation is only effective down to half the initial pressure, the loss amounts to barely 1 per cent. of the total adiabatic drop. The article is illustrated.

C. J. G.

Theory of the Centrifugal Pump. J. HERBERT.

(Zeitschrift für das Gesamte Turbinenwesen, Berlin, 1913, vol. 10, pp. 481–487, 500–506, 519–525, and 529–534.)

This article deals with trials made at the Technical High School, Darmstadt, to determine the effect of the various methods of regulating the output of a centrifugal pump, and to ascertain also whether the proportional law is generally applicable. The pump tested, of which a drawing is given, had an inlet of 150 millimetres, and was driven by a 25-HP. motor, capable of speed-regulation 1,200 to 1,650 revolutions per minute. The equation relating "Q" the delivery with "H" the head, and the two proportional equations are derived, viz.: $H = k_1 n^2 - k_2 n Q - k_3 Q^2$; $Q = \frac{Q_1 n}{n_1}$; $H = \frac{H_1 n^2}{n_1{}^2}$. The discharge was regulated by (1) throttling at the outlet, (2) alteration in the guide-blades, (3) partial closing of the wheel-passages, and (4) change of speed, the trials being made at speeds of 1,200, 1,300, 1,375 and 1,500 revolutions per minute. The results are given in tabular and graphical form. In all cases the best efficiency was approximately 75 per cent., and was obtained with a discharge of about 30 cubic metres per second, with generally a slight diminution of efficiency with increase of speed. There was a great and increasing drop of efficiency after two-thirds discharge. By closing three out of the nine guide-passages in the runner, much better efficiencies were obtained at light loads, resulting in a much better efficiency-curve. The results obtained with the various methods of regulating the discharge are also plotted on diagrams each for the same speed. It is shown that the proportional law does not hold for the whole range of discharge and head, and fails so soon as the delivery is sufficient to produce turbulence. Tests by Barbezat and Reichel are quoted in support of this statement.

H. R. S.

Characteristics and Regulation of Turbo Air-Compressors.

G. A. SVHOEPFINN.

(Zeitschrift für das Gesamte Turbinenwesen, Berlin, 1913, vol. 10, pp. 465–467.)

If the discharge of a turbo-compressor is throttled beyond a certain or critical point the compressed-air is expanded back into the suction, and cyclical variations of pressure take place. The conditions at this critical point are investigated and a diagram is drawn by first plotting, as a rising straight line, the theoretical head-discharge characteristic on a discharge-base. With the exception of the bearing losses, all the losses are converted into heat, which is carried away by the issuing air. By equating the losses to the heat in the air a curve is obtained, the intersection of which, with the theoretical head-discharge straight line, gives the volume of discharge at the critical point. In a numerical example in which the normal delivery is 2·5 cubic metres per second, the critical point is found to be at 2 cubic metres per second, and it is shown that the only practical means of overcoming this difficulty is to provide a by-pass, through which the overplus air can flow back to the suction.

H. R. S.

Technical and Commercial Results of Steam-Turbine Operation.

K. HOEFER.

(Zeitschrift für das Gesamte Turbinenwesen, Berlin, 1913, vol. 10, pp. 513-519, 534-539, 549-553, 564-567.)

In order to ascertain the progress made in steam-turbine design and manufacture, Professer Jossé sent out a series of questions to 130 manufacturers and users. The answers received are presented in this article in a series of Tables, the main figures of which are also plotted. For the purposes of classification, five separate types of steam-turbines are considered: (1) Re-action turbines; (2) Re-action turbines, with one high-pressure impulse wheel; (3) Pure "equal-pressure" turbines (Zolly System); (4) Equal-pressure turbines, with one high-pressure Curtis element; and (5) Equal-pressure turbines, consisting of Curtis elements only. The turbines are also divided into two groups: "moderate" up to 1,000 kilowatts, and "large" 1,000 to 20,000 kilowatts. The inquiry starts in 1902 and includes turbines built in 1912. Whereas the average output of turbines in 1902 was 700 kilowatts, in 1912 it was over 4,000 kilowatts. There is a tendency to increase speed, at any rate when driving alternating-current machines. It is also shown that a greater number of turbines are now being built with a steam-velocity approximating to that of sound. As regards economy, there are several Tables for the various groups referred to above, in which are stated the steam-consumption per kilowatt, the efficiency-ratio, including dynamo-losses, both as determined on trial and as guaranteed. A Table gives the ratio of steam-consumption at fractional loads as compared with that at full load. Information is also given as to steam-consumption, coal-consumption, oil and other stores for a number of power-stations of 500 to 60,000 kilowatts. Particulars of condensing arrangements are given, and it is stated that 43 per cent. of the total cost is due to the steam-turbine itself, 31 per cent. to the generator, and 26 per cent. to the condensing-plant.

H. R. S.

Railways and Navigation in the Cameroons.

F. Michell and Fr. Lenz.

(Annalen für Gewerbe und Bauwesen, Berlin, 1914, vol. 74, pp. 23-27.)

The results of an exploration of the Cameroons, under the leadership of Mr. F. Michell, considered by the German Colonial Economic Committee, are set forth and explained by reference to a map. The methods of facilitating the navigation of the river Njong, which is naturally divided into two distinct sections, are discussed. The first section, which includes the stretch between M'Balmajo, the future terminus of the Cameroons Central Railway, and Ajoshöhe, a distance of about 140 miles, can, by means of weirs and embanking, be rendered navigable all the year round. A further length of about 64 miles up to Abongmbang can be made available for small motor-boats if regulation and canalization be undertaken; but the land traversed is marshy, and during the dry season of 2 to 3 months it might be impassable. For 80-ton stern-wheel steamers, with a draught not exceeding 40 inches, the river might be improved at a cost of about £175,000, as compared with £875,000, the estimated expense of building the railway, or a saving in round figures of £700,000. In a similar way the Commission examined the rivers Dume, Kadei and Sangha, and they make proposals for the requisite works. The Northern Railway in the Colony is a private undertaking, with a Government guarantee for £550,000. There is a preference capital of £282,000, and the results of the working for the first year (1912) are considered. The Cameroons Midland Railway will run from Duala to the river Njong, a distance of about 177 miles, of which 80¾ miles are open for traffic. The prolongation of the line in the direction of Lake Tchad depends on the possibility of making certain improvements in the navigation of the rivers already mentioned. The extension of the Northern Railway for a length of some 560 miles to Garua is also considered. The problem of railway-construction in this colony is rendered extremely difficult by the mountainous regions and the character of the interior traversed. It will probably be found necessary to follow the watersheds of the main rivers. The river Logone has not yet been examined, but a great length is navigable. The possibility of linking up the railways in the Cameroons with the French-Congo railway-system is considered.

G. R. R.

New Zealand Railways—1912–1913.

(Report of the Minister for Railways, 31st March, 1913.)

	1913	1912
Mileage[1]	2,860	2,808
Average mileage for year	2,840	2,801
	£	£
Revenue	3,971,002	3,676,509
Working-expenses	2,705,609	2,465,896
Net revenue	1,265,393	1,210,613
Percentage of profit to capital invested	4·04	3·98
„ „ working-expenses to gross receipts	68·13	67·07

	Per Open Mile. £	Per Train-Mile. d.	Per Open Mile. £	Per Train-Mile. d.
Earnings	1,400	105·50	1,314	105·25
Details of working-expenses—				
Maintenance	270·61	20·38	263·46	21·08
Locomotive	294·39	22·18	266·28	21·31
Carriages and wagons	79·91	6·02	74·87	5·99
Traffic	271·70	20·47	240·20	19·22
General	37·07	2·79	36·26	2·92
Totals	953·68	71·84	881·07	70·52
Net revenue	446·32	33·66	432·93	34·73

	1913	1912
Passenger-journeys	13,123,879	11,891,134
Goods-tonnage	5,957,005	5,599,765
Live-stock tonnage	289,123	288,152
Train-mileage	9,016,224	8,371,687
Capital expenditure, including unopened lines	£33,831,783	£32,689,179
Rolling-stock—		
Locomotives	513	493
Passenger-cars	1,282	1,212
Trucks and vans	19,015	18,521

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[1] The gauge of the New Zealand railways is 3 feet 6 inches.

A Table compares New Zealand railway statistics with those of the various States of Australia. In this, counting maximum for receipts, gross and net, and minimum for expenses and percentage on gross receipts, the following States stand first per train-mile:—

Gross earnings	New Zealand.
Working-expenses	Queensland.
Net profits	New Zealand.
Percentage on gross receipts	South Australia.

The Minister remarks on the fact, which he finds to exist on nearly all railway systems as well as in New Zealand, of the increasing proportion of expenses to gross receipts, due to advance of wages and shortening of hours, increase of cost of fuel, coinciding with more lavish accommodation for the public, and he cites examples from the reports of the Canadian, United States and Australian lines.

C. O. B.

Tasmanian Railways—1912-1913.

(Report of the Commissioner, 30th June, 1913.)

	1913	1912
Average miles[1] open	507·75	502·75
	£	£
Earnings	327,113	312,786
Working-expenses	221,172	221,172
Net revenue	109,756	91,614
Percentage of working-expenses to gross receipts	66·44	70·71
Interest on capital	2·49	2·15
Passenger-journeys	1,649,539	1,715,464
Goods-tonnage	477,393	452,098
Live-stock tonnage	17,561	17,757

	Per Open Mile.	Per Train-Mile.	Per Open Mile.	Per Train-Mile.
	£	*d.*	£	*d.*
Receipts	644·24	77·99	622·15	71·73
Expenditure	428·07	51·82	439·92	50·72
Net receipts	216·17	26·17	182·23	21·01

	1913	1912
Division of expenditure—	£	£
Maintenance	58,534	63,669
Locomotive and carriages	86,301	88,254
Traffic	60,820	57,570
General	11,703	11,679
Total	217,358	221,172
Train-mileage	1,006,508	1,046,479
Engine-mileage	1,245,885	1,293,059
Average passenger-mileage	21·58	19·99
„ ton-mileage	39·67	39·09
	£	£
Cost of construction and equipment	4,400,292	4,253,013
Do. per mile	8,674	8,583

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[1] Most of the Tasmanian railways are on the 3-foot 6-inch, the remainder being on the 2-foot gauge. The mileage of each is not given in the Report.

	1913		1912	
	Gauge.		Gauge.	
Rolling-stock—	3 ft. 6 in.	2 ft.	3 ft. 6 in.	2 ft.
Locomotives	72	7	..	..
Carriages and vans	122	3	..	..
Wagons	1,680	80	..	..

Tables show comparative statistical figures of the Tasmanian and Australian State lines.

Victorian Railways—1912–1913.

(Report of the Commissioners, 30th June, 1913.)

Mileage, 30th June—	1913	1912
5-foot 3-inch gauge	3,868	3,500
„ „ sidings	672	644
Equivalent to single line, including sidings	4,539	4,485
2-foot 6-inch gauge	122	121
„ „ sidings	8	7
Equivalent to single line, including sidings	130	129
Under construction, 5-foot 3-inch gauge	212	196
Authorized, 5-foot 3-inch gauge	224	53
	£	£
Gross revenue	5,205,442	5,218,967
Working-expenses	3,476,957	3,310,484
Net revenue	1,728,485	1,908,483
Percentage of working-expenses to gross revenue	66·79	63·43
Passenger-journeys, country	8,510,261	8,071,436
„ „ suburban	103,003,647	96,163,296
Goods-tonnage	4,738,984	4,886,001
Live-stock tonnage	411,420	411,684
Train-mileage	14,234,550	13,836,375

	Per Open Mile.	Per Train-Mile.	Per Open Mile.	Per Train-Mile.
	£	d.	£	d.
Revenue	1,430	87·77	1,473	90·53
Working-expenses	955	58·62	934	57·42
Net revenue	475	29·15	539	33·11

Details of working-expenses per train-mile—	d.	d.
Maintenance	15·69	15·49
Rolling-stock branch	24·71	24·12
Traffic	15·98	15·63
General	2·24	2·18
Total	58·62	57·42
Capital expenditure	£47,656,469	£45,897,163

Rolling-stock—	5-foot 3-inch gauge.	2-foot 6-inch gauge.	
Locomotives	656	12	—
Coaches	2,047	25	—
Trucks	15,658	210	—
		Lbs.	
Total tractive capacity of locomotives		10,971,103	—

The Commissioners account for decreased profits by the Government decision that there should be at least one train daily between Melbourne and every town having 2,000 inhabitants, by increased wages, higher cost of coal, and concessions to the staff due to higher cost of living. In consequence of the projected electrification of suburban railways, an electrical engineer's branch was added to the Department on the 1st May, 1913.

C. O. B.

Western Australian Railways—1912–1913.

(Commissioner's Report for the year ending 30th June, 1913.)

	1913	1912
Mileage,[1] 30th June—	Miles.	Miles.
Double	106	106
Single	2,854	2,598
Sidings	296	279
Average miles worked	2,783	2,471
Completed during year	256	..
Under construction or authorized	614	..
	£	£
Gross earnings	2,037,853	1,884,604
Working-expenses	1,506,600	1,343,977
Net revenue	531,253	540,627
Percentage of working-expenses to gross revenue	73·93	71·31
	d.	d.
Receipts per train-mile	86·98	86·53
Working-expenses per train-mile	64·30	61·71
Passenger-journeys	17,920,096	16,390,261
Goods-tonnage	3,217,023	2,791,866
Live-stock tonnage	65,338	61,770
Train-mileage	5,623,132	5,227,311
Details of working-expenses per train-mile—	d.	d.
Maintenance	12·30	11·85
Locomotive	31·89	30·11
Signalling	0·67	0·74
Electrical	0·78	0·79
Traffic	16·96	16·49
General	1·70	1·73
Total	64·30	61·71
Net receipts	22·68	23·82
Number of employees	7,907	7,464
	£	£
Capital expenditure	14,913,128	13,233,093
Interest	505,925	439,153
Rolling-stock—		
Locomotives	386	359
Carriages and vans	552	510
Wagons	8,895	7,985

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[1] The gauge of these railways is 3 feet 6 inches.

The Commissioner again criticizes the inefficiency of stability in the construction of the light lines proposed to be handed over to him by the Public Works Department, noting one exception, and draws attention to the extent to which the growth of railway-construction is exceeding that of population. He also animadverts on the growing expenditure on wages and material, combined with reduction in charges which have been forced on the Railway Department as matters of policy. The cost of coal and water-supply per train-mile in Western Australia is shown by a Table to be 9·47*d.*, and in the four other States 6·22*d.*, 4·47*d.*, 5·71*d.* and 4·59*d.*

C. O. B.

Merkur Mountain-Railway at Baden-Baden.

Professor W. EBERHARDT.

(Deutsche Bauzeitung, Berlin, 1914, vol. 48, pp. 6 *et seq.*)

The top of the Staufenberg or Merkur, 1,650 feet above the valley, affords the finest view near Baden-Baden. In 1909 the Author, with others, submitted a scheme for an electrically-driven rope-railway, which was approved by the State, and its construction was begun in the summer of 1912 at the cost of the municipality. In a length of 2·22 miles the line rises about 410 feet, the least gradient is 23·5 per cent. and the greatest 54 per cent. Details of the construction of the road-bed are fully given, but these do not greatly differ from those already well known in Switzerland. The chief point of interest is the electrically-driven rope-transmission. Direct current is obtained from the public mains at a pressure of 600 volts, and this supplies an average of 64·2 HP. and also charges a secondary battery used for lighting the station and the restaurant at the summit. The battery also acts as a reserve of power to prevent violent fluctuations of demand on the public mains as the peak-load rises to 90 HP. Rotary transformers are employed which furnish current at 160 volts for all purposes. Each car weighs 6·25 tons empty and carries fifty passengers, so that the weight loaded may be assumed as 10 tons. The greatest pull on the rope with a fully-loaded car on the steepest incline is 5 tons, and the rope has an ultimate tensile strength of 50 tons. The installation is designed for four to five journeys per hour at a speed of 4·5 miles per hour. The article is illustrated, and a detailed description of the mechanism of the car is given.

E. R. D.

Construction of the Chur–Arosa Railway.

(Schweizerische Bauzeitung, Zürich, 1913, vol. 62, pp. 281-286.)

This article describes the construction of the line. Good progress has been made with the Arosa tunnel, but instead of gneiss rock, which was expected, a moraine was found. The Calfreiser viaduct, which is illustrated, has two principal spans of 82 feet and 59 feet, built of ballast concrete blocks, and four smaller spans of 39·3 feet and 19·7 feet, built of mass concrete, with arches of reinforced concrete. Special care was taken with the waterproof coating of the arches. The Castiel viaduct has three arches, of 82 feet span and 174 feet high, and is the most important masonry bridge on the line. The Bärenfellen tunnel is 272 yards long and is S-shaped in plan, and on a gradient rising 6 per 1,000, and this is followed by a length of about 1·24 mile, so poor in building-stone that concrete had to be used for the retaining-walls, abutments, etc. Beyond this point is the Sandgrind tunnel, which is followed by a stretch 4·35 miles in length of moraine up to Langwies, and only at two points could suitable stone be found. One of the largest structures on the line is Gründjetobel bridge, near Langwies, of which the principal arch has a span of 282 feet; the plans were accepted on the 21st June, 1913, the wooden falsework was completed on the 26th August, and the arch by the 15th September. The total length of the bridge is 157 yards, and the height 150 feet. The Langwies viaduct has a central arch 315 feet wide, and 204 feet high; the total length is 310 yards, and it is said to be the largest structure built of concrete blocks in Switzerland.

E. R. D.

Lötschberg Electric Railway.[1]

(Elektrotechnische Zeitschrift, Berlin, 1913, vol. 34, pp. 1275-1279, 1311-1314, 1340-1343.)

A general description of this line is given, illustrated by numerous drawings and photographs. Between Frütigen and Kandersteg the line has a figure-8 shape on plan in order to rise 420 metres at the maximum ruling gradient of 27 per cent. The electric locomotives put into service in 1910 have shown that single-phase current is perfectly suitable for main-line traffic, especially for heavy traffic over heavy gradients. The more recent locomotives can develop 2,500 HP. for 1½ hour when running at 50 kilometres per hour: they are of the 2–10–2 type, the draw-bar pull is 10,000 kilograms, and they can deal with 310 tons behind them on the 27 per cent. gradient. The current is collected by a pantograph at 15,000 volts 15 cycles, and is transformed down to

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[1] Minutes of Proceedings Inst. C.E., vols. clxxvii, p. 310; clxxxi, p. 504; cxcii, p. 344; cxciii, p. 389; cxcv, p. 439; and following Abstract.

420 volts. There are two sets of transformer regulating gear, and they can work together or independently. There are also tappings on the secondary transformer connecting to a special regulator, which is described and illustrated. The contacts of this regulator are cleaned after every 6,000 kilometres run. The motors weigh 14 tons, and the speed is reduced in the ratio of 1 to 2·23 by means of double helical gear, driving a jack-shaft connected to the coupling-rods. An outline drawing gives plan, longitudinal and cross-sections, and the principal dimensions of a locomotive and the complete diagrammatic electrical connections are also given.

H. R. S.

Electric Traction on the Bern-Lötschberg-Simplon Railway.[1]

L. Thormann.

(Schweizerische Bauzeitung, Zürich, 1913, vol. 63, pp. 19-54.)

The Author points out that as the Bern-Lötschberg-Simplon line has been worked by electricity since the middle of July, 1913, valuable data are now available, which differ widely from those obtained with the much lighter train on the Spiez-Frütigen section. No experience had been obtained previously of the life of overhead wires in long tunnels such as the Lötschberg, which is 9 miles in length. As no test-period was allowed, but regular service began at once, it is not surprising that many initial difficulties arose. The gradients up to the Lötschberg are 27 per cent., and trains weighing 300 tons have to be taken up at a speed of 31 miles per hour. In each direction there pass every day five express trains, three passenger-trains, four regular goods-trains, and others according to the demand. The electric locomotives were built jointly by the Oerlikon Company and the Swiss Locomotive Works at Winterthur, and weigh 107 tons in working order. The energy is supplied by the Bern Power Company from their works at Spiez and Kandergrund. The trial-runs showed that high-speed series motors with spur-gearing were suitable. The new six-wheel coupled locomotives are capable of exerting 2,500 HP. and a draw-bar pull of 22,000 lbs. at a speed of 31 miles per hour, and are required to develop this output for 1½ hour, without overheating, and within 24 hours to make three return journeys between Spiez and Brig, with the usual stops at stations. The distance between Spiez and Brig is 46·5 miles, and the difference in level between Spiez and the summit in the Lötschberg tunnel is 2,050 feet. The electric and mechanical portions of the locomotive are described and illustrated in great detail; the 15,000-volt single-phase alternating-current is collected from the overhead wire by two bows and transformed to 420 volts, and at full load the motors take 2,700 amperes. Characteristic curves are given and also diagrams of connections on the locomotives. E. R. D.

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[1] Minutes of Proceedings Inst. C.E., vols. clxxvii, 310 ; clxxxi, p. 504 ; cxcii, p. 344 ; cxciii, p. 389 ; cxcv, p. 439 ; and preceding Abstract.

Electrification of the Swiss Railways. J. Reyval.

(La Lumière Électrique, Paris, 1914, vol. 25, pp. 33–41, 65–68, 106–111.)

Electrification of railways is especially advantageous in Switzerland owing to the extent of water-power and the dearness of imported coal. A Commission has recently studied the question and has decided in favour of single-phase transmission at 15,000 volts, and the reasons leading to this decision are given in this article. It was considered satisfactory if the starting effort were double the normal effort, and then gradually reduced during acceleration. Characteristics of an "Ideal" motor, providing this acceleration, are given, together with those of a steam-locomotive, which falls below it, of a continuous-current series motor which is above, and of a single-phase motor which is almost coincident. It was determined that the maximum load would be about 3½ times the mean load, and estimates were prepared showing the cost of storing energy during light load by supplying batteries, in the case of continuous current at 3,000 volts, and utilizing hydraulic means, namely, pumping into a reservoir, in the case of single-phase high-voltage transmission. An abstract of these estimates shows that the single-phase method of storage of energy is considerably the cheaper. A comparative estimate is given of the capital and fuel cost for single-phase 15-cycle, and for three-phase 50-cycle transmission, (1) when the traffic is 10 per cent. greater than at present, and (2) when it is 50 per cent. greater. In both cases this estimate shows a saving of about 15 per cent. in respect of the single-phase system. The article concludes with a detailed account, with costs, for the Gothard Railway. A comparison is made between steam-traction in 1904 and in 1907, and single-phase electric traction. The horse-power required for different sections of the line is given, with the annual amount of energy, and the horse-power to be installed at the three central power-stations of Göschenen, Amsteg and Ritom. H. R. S.

2,400-*Volt Railway-Electrification.* H. M. Hobart.

Trunk-Line Electrification. C. P. Kayler.

(Discussion.)

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 2122–2147.)

The trend of the discussion was to show that neither of the Authors had made out a case for greater economy resulting from the electrification of main lines. Mr. A. H. Badcock said the statement that the hydro-electric companies' mains would only be exposed to an additional fluctuation of a couple of thousand kilowatts for a few freight-trains, was incorrect, that each freight-train would require 4,000 to 4,500 kilowatts, and that so far no power company had been found willing to face such loads being thrown instantly on or off their system. Mr. H. Y. Hall and Mr. G. W. Welsh pointed out that an insufficient number of electric locomotives had been assumed, and that many items in the cost of electrification had been under-estimated. For instance, the double-circuit steel-tower transmission-line should be taken at 6,000, as against 5,000 dollars per mile, and the double-span construction at 4,000 instead of 2,600 dollars per mile. Altogether the total first costs would be about 12,698,000 dollars, instead of 9,972,000 dollars. They also stated that Mr. Hobart had much over-estimated the cost of the steam-locomotives, and as regards power his locomotives were only two-thirds as powerful as those in actual service.

H. R. S.

Diesel Oil-Locomotive. Professor P. OSTERTAG.

(Schweizerische Bauzeitung, Zürich, 1913, vol. 62, pp. 297-302.)

The Author describes this as the first thermo-locomotive, and states that the first vessel fitted with a Diesel engine was built by Sulzer Bros. in 1906, and has led to the use of similar engines for marine purposes. The employment of the Diesel engine for a locomotive was a much more difficult problem, but the Author considers that it has now been solved. The new locomotive was tested in the spring of 1913 on the Winterthur–Romanshorn line. The total length over buffers is 54·5 feet, the weight in working order 95 tons, and the engine has four coupled wheels 3·28 feet in diameter and a four-wheeled bogie at each end. The whole of the mechanism is covered in, and in each corner of the cab is placed a vessel, three for cooling water and one for oil. There are two Diesel engines, both driving on to a central shaft, from which the driving-wheels are actuated by connecting-rods, and an auxiliary engine which works the air-compressors, and this air is used for starting the locomotive and driving it up to a speed of 5 or 6 miles per hour. The main engine has four cylinders and develops 1,200 HP. at 62 miles per hour, while the auxiliary engine can develop 250 HP. Indicator diagrams are reproduced and the locomotive is illustrated in this article. After satisfactory trials of the locomotive in Switzerland it travelled to Berlin by the Basel–Strassburg–Worms–Nordhausen route at speeds of 12·4 to 62 miles per hour, drawing a train and ordinary steam-locomotive.

E. R. D.

Mountain Type Locomotives for the Missouri–Pacific Railway.

(Railway and Engineering Review, Chicago, 1913, vol. 53, pp. 1013-1014.)

Seven of these engines have been provided to deal with heavy passenger-traffic on a 165-mile division of the Missouri–Pacific Railway, leaving St. Louis and crossing the Ozark Mountains. It contains several long gradients of 1 in 62·6 to 1 in 250. These 4–8–2 locomotives, which replace those of the Pacific type, draw a tonnage behind tender of 820 short tons up the former gradient at 18 miles per hour. The weight with tender is 457,500 lbs. with a maximum weight on drivers of 210,000 lbs. and the tractive effort is 50,400 lbs. There are several illustrations and two Tables, one accentuating the superiority of the new over the superseded locomotives, and the other giving details of dimensions, weight, power, fuel, capacity, etc., of the new type.

C. O. B.

Pacific Locomotive of the Paris–Lyon–Méditerranée Company.

H. Sabourin.

(La Technique Moderne, Paris, 1913, vol. 7, pp. 310-314.)

This locomotive is a four-cylinder compound of the "Pacific" 4–6–2 type.[1] Originally saturated steam was used, but it has now been fitted with the Schmidt superheater. Full particulars of the design of the locomotive, and of many of its parts, are given, together with a description of the materials used. To free the axle of the Bissel truck there is a sloping grate, and the plates of the fire-box have been inclined, so as to push the boiler forward. The pistons are of steel, the diameters being 420 and 620 millimetres for the high-pressure and the low-pressure cylinders respectively. Piston-valves are used, actuated by Walschaert gear. There is a detailed drawing of the Bissel truck with many of the dimensions figured. A complete tabular statement of all the main dimensions and weights of the engine is also given. Several tests have been made with this engine, and the main results are given. For instance, when drawing 487 tons behind the tender the indicated horse-power was 1,885, the expenditure of coal 1·09 kilogram per indicated horse-power and the water-consumption 8·39 kilograms. The figures for draw-bar horse-power were 1·63 and 12·45 respectively.

H. R. S.

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[1] *Ante*, p. 205.

Pacific Type Locomotives, Central Railway of Georgia.

(Railway and Engineering Review, Chicago, 1913, vol. 53, pp. 1080–1081.)

The passenger-engines put in service, six in 1912 and, after experience, four more recently, are stated to represent the most advanced types, more especially as regards boiler and fire-box design, the latter being of the Gaines type. Each of the new engines, only slightly modified from the earlier ones, exerts a tractive force of 34,800 lbs., and, with 138,000 lbs. on driving-wheels, the ratio of adhesion is approximately 4 to 1. The total equivalent heating-surface is 3,596 square feet, or 267 square feet per cubic foot of cylinder-volume, while the ratio of tractive force in pounds to equivalent heating-surface in square feet is 9·7. The driving-wheels are 69 inches in diameter, so that great acceleration and heavy duty are combined. The special features are the boiler and fire-box. The latter is 11 feet long and 7 feet wide. A fire-brick wall with its front face 31 inches behind the tube sheet, is built across the back of the fire-box, dividing the latter into two compartments. On the top of this wall is placed a ledge which projects 6 inches towards the rear of the fire-box. The wall is cored with five vertical ducts, through which the air is drawn and discharged in a backward direction under the ledge. This air mingles with the gases just as they pass over the arch, and furnishes the oxygen needed to complete combustion. At the same time the projecting ledge tends to deflect the gases against the back sheet and the rear of the crown sheet, and thus increases the value of these parts as heating-surface. The grate is described, and the article concludes with a Table of dimensions, weights, type, pressure, fuel, and coal- and water-capacity. There are several illustrations, including one of the Gaines combustion-chambers.

C. O. B.

Locomotive Blast-Pipes and Chimneys. G. STRAHL.

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1913, vol. 57, pp. 1739–1748.)

The present calculations are based on experiments made by the Author published in 1911[1] and intended to amplify Zeuner's blast-pipe theory.[2] The Central Railway Board in Berlin had since adopted the Author's suggestion to test blast-pipes with reference to maximum steaming results, before the locomotive is placed on the road. It was found that the blast-pipes and chimney-openings of the latest types of superheater-locomotives were too small. The

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[1] *Organ für die Fortschritte des Eisenbahnwesens*, 1911, p. 321 *et seq.*

[2] Dr. G. Zeuner, "Das Lokomotivenblasrohr," Zürich, 1913, and "Die Wirkung des Blasrohrapparates bei Locomotiven mit konisch-divergenter Esse," *Civilingenieur*, 1871, p. 1.

Author gives a formula including the various resistances to motion of the gases and relates this to the inertia equation of the steam. These formulas are then applied to an existing design of chimney of a 4–6–0 superheated, compound express-locomotive, and it is shown that the blast-pipe opening should be increased from 5·715 to 5·785 inches diameter, the inlet opening of the chimney-stack from 16·35 inches to 16·95 inches and the outlet from 19·87 inches to 21·2 inches diameter, to obtain satisfactory results. A Table shows similar particulars for ten different locomotives. The Author concludes that Zeuner's theory, although correct in principle, gives too small a diameter for stack and blast-openings. From the theory of steam-generation a formula for the efficiency of the blast-pipe is deduced, which takes into account the steaming capacity and efficiency of the boiler, which in turn depend on the proportion of heating to grate-area. The results show that the best stack is obtained with the widest possible blast-pipe, which, in order to obtain the maximum effect, should be placed as low as possible. The size of the smoke-box is the practical limit to which this rule can be applied.

C. J. G.

Roller-Bearings on Coaches.

(Railway Age Gazette, New York and Chicago, 1914, vol. 88, pp. 19-22.)

After a long series of experiments roller-bearings were applied to a 25-ton inter-urban car and several others, effecting a saving of about 17 per cent. in power-consumption. Hitherto, the application of the system to steam railways has been very limited. The results of the savings effected are given in detail, followed by a description of the device as used on the Bangor–Aristook street-railway, on 70-foot coaches and inter-urban cars, which show reduced resistance and low maintenance cost. There are a great many illustrations of this type, and a diagram shows the reduction in fuel-consumption on the old as against the new system.

C. O. B.

Rail-Corrugation. C. M. Gidanski.

(Electric Railway Journal, New York, 1913, vol. 42, pp. 1322-1326.)

The Author describes in great detail, with illustrations, the corrugation on the Brooklyn Rapid Transit System. He then shows how corrugation increases, and points out that an important characteristic of all corrugation is that the axis of the crest, transverse to the longitudinal axis of the rail, is, in almost all cases, oblique to the gauge-line in a greater or less degree, and after dealing with irregular and regular corrugations, and the effect of braking, he comes to the causes. These are generally attributed to (1) lateral slipping and oscillation, due to distortion of trucks and play in the parts; (2) wide gauge and loose track vibration; (3) application of brakes; (4) inequality of homologous-diameter elements of a pair of wheels on the same axle; (5) rigidity of road-bed; (6) deficiency in the elasticity of rails to resist loading; (7) tires being harder than rails; and (8) cold-rolling by car-wheels going over the track. The Author deals with these causes seriatim, rejecting Nos. 1, 2, 3 and 4 for reasons given at length; No. 5 is considered insignificant; Nos. 6 and 7 are allowed, but No. 8 stands first as a cause, and the Author shows that British engineers have correctly described the chief cause of corrugation.[1] The article concludes by pointing out that dish-joints are owing to the same cause, and that an elastic road-bed is the best remedy.

C. O. B.

Note on Staggered and Squared Joints, as applied to Railway-Tracks. A. J. Beaton.

(Minutes of Proceedings of the South African Society of Civil Engineers, 1913.)

The Author claims superiority for the squared joint. The contentions of the advocates of the staggered joint are shown to be that stability is better secured by placing the solid section of one rail opposite the joint of its companion, especially lateral stability, as the liability to divergence at any given point caused by it is minimized by having continuity on the other side, this being a resistant to any tendency to horizontal movement, especially in sharp curvature. As to vertical displacement, it is claimed that the continuous rail centre opposite a joint prevents the wheels from striking the ends of the rails so hard at the opposite joint.

As to the first point, it is stated that, if the rails are truly curved, lateral tendency is equally resisted on both systems; and, as to the second, the claim is a fallacy amply demonstrated by experience. These arguments are then elaborated, and, as regards vertical deformation, it is shown that, with the best type of joint, its incidence is the weakest part of the road, hence there is a depression on the staggered-joint road at one side only, leading to a transverse lurching of the vehicle, which is intensified by the succeeding depression on the other side, and an oscillation is set up, this being felt on the South African 3-foot 6-inch gauge more than on broader ones, owing to the greater overhang. On the squared road, though vertical vibration is set up, it is equal at each side, and is neutralized by the reaction of the springs of the rolling-stock. On straight roads, the causes of the tendency to vertical vibration are explained, and Professor Omori, the Director of the Seismological Institute of Tokyo is quoted as follows: "It is possible that the vertical shock communicated by a joint to the wheel may increase with the velocity up to a certain value, after which it would decrease. If, indeed, the speed of the train were infinitely great the wheels would pass horizontally over the joint, and would thus experience no vertical shock." This, however, is a theoretically perfect condition which can never be attained in practice.

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[1] See *Electric Railway Journal*, 30 September, 1911.

On the whole, the argument as to mechanical effect may be abstracted by stating that the advantages of staggering as regards horizontal deformation can be counteracted by effective plate-laying and maintenance, while the disadvantages as regards vertical deformation are inherent in the system; also, that the horizontal stresses are less important, and greatly inferior in amount to the vertical stresses. An important factor against the staggered road is the extra expense, for, in order to obtain uniform sleeper spacing, an additional sleeper for each rail-length is required, with more closure rails and extra joints, involving additional maintenance charges. The extra first cost the Author puts at £50 to £60 per mile. There is an erroneous idea that more sleepers are required on sharp curves than elsewhere, but this provision is to resist shocks at the ends of the curves, which are eliminated by the modern practice of introducing transition-curves, and these are strongly advocated. Examples are given, where the oscillation due to the staggered system was so great that it had to be replaced by a square-jointed road, and a discussion at the Paris International Railway Congress is referred to, in which thirty-seven railway companies preferred the squared system, the Eastern Railway of France and one line in Belgium using the staggered joint. The authorities of the former railway, however, had notified that there was a tendency to revert to the squared system.

In the discussion which followed, Mr. Tudhope said that, after experience of both systems, the amount of vibration was less with the staggered joint, owing to less liability of synchronism between the springiness of the wheels and the give of the rail, which might occur with the squared joint, the vibration being checked by the irregularity of the staggering. He admitted the greater expense in the matter of sleepers, but set against it that of less rail-cutting. Mr. H. H. Elliott agreed with the Author as to the advantage of squared joints on straight sections, but differed as to their superiority on curves for reasons given in the Paper. He added that staggering was universal on sharp curves on the South African railways. Mr. Heatlie followed on the same lines, contending that the perfect road the Author assumed is not always attainable, especially when economy in maintenance is enforced. He quoted Molesworth as stating, that "Rails which do not break joint have only 70 per cent. of the lateral strength of those which break joint," and he claimed that the lateral deformation in curves caused by centrifugal force is resisted at the outer rail-joint by the sleeper-connection of the continuous rail on the inner side.

The Author, in reply, said that extra rail-cutting was unnecessary, as there was always a percentage of short rails supplied. He considered Molesworth on the subject of staggered joints was out of date, and elaborated further his reasons for objecting to staggered joints on curves.

C. O. B.

Cast-Weld Joints and Steel Ties in Brooklyn.

(Electric Railway Journal, New York, 1913, vol. 42, pp. 920-924.)

These joints, superseding riveted joints, were installed on fourteen important lines of the Brooklyn Rapid Transit System in 1911, and have since been reported on favourably. The process is that first two holes are drilled in the end of each abutting rail to the standard single-road spacing of 2½ inches and 4 inches, after which the track is lined through by the temporary application of standard fish-plates with two bolts per plate. The next step is to remove the plates and apply a sand-blast to obtain a good surface. Cold-rolled steel pins are then inserted in the two holes nearest the end, with a ¼-inch groove near either end. They are used to assist in distributing the tension-strains throughout the metal of the weld. They also serve to unite mechanically the two halves of the joint casting. The moulds, which are now put in place, consist of a right-hand and left-hand piece for the sides of the rail, and a top piece which fits the head of the rail. The side pieces are then secured by means of an inverted C-shaped clamp. The article describes the various devices to hold the head of the rails in surface, to help to prevent cambering, to dissipate heat, and to ensure gradual pouring of the metal. The cupola equipment is placed on a car as near to the operation as possible. About twenty-four to thirty joints are welded in a day. Tests show conductivity to be equal to 3·37 feet of rail. These joints are placed square instead of staggered. The cost of the cast-weld joint is 15*s*., while the superseded riveted joint cost £1 1*s*. A Table shows details of the former. A description of the steel sleepers recently put in, with a novel attachment to the rail, is given. The article is illustrated.

C. O. B.

Question of Rail-Fastenings. WAAS.

(Annalen für Gewerbe und Bauwesen, Berlin, 1913, vol. 73, pp. 166-169.)

Some account is given of the methods of fastening wide-flanged foot-rails to the sleeper, and it is shown that by the adoption of a sound system a very considerable saving is effected in upkeep, as also in the life of the rail. If it can be proved that the method of fastening employed at the same time prevents rail-creeping, a still greater economy results. A graphic diagram shows the oscillations of a rail under a passing train, and it is pointed out that the object of the rail-attachment is partly to facilitate the transmission of the rail-oscillations to the sleeper or substructure. Diagrams indicate the pressure of a rolling wagon-wheel, and it is shown that forces of several different kinds are exerted on the rail by the wheel in motion. In reference to this subject an illustration is given of the rail-fastenings in use on the Austrian Southern Railway and on the Austrian State Railway, which are reported to be effective in the prevention of creeping. An important feature is that the grip on both extremities of the flange is similar. It is claimed that the best means of guarding against creeping is to adopt attachments which tend to increase as far as possible the friction between the rail-base and the plate on which it rests. Various improved rail-attachments on the Haarmann and other systems are illustrated. In one case the length of the clamping-plate is considerably increased and the number of the holding-down bolts is doubled. A special rail-fastening, applicable to the case of wrought-iron sleepers, is also described and illustrated.

G. R. R.

Extension of the Block System on the State Railways of France.

J. NETTER.

(La Technique Moderne, Paris, 1914, vol. 8, pp. 1-5 and 54-61.)

It is the intention to fit 1,500 kilometres of the State Railways in France with the block system, on those lines where the difficulty of conforming to the rule that trains shall not follow each other at closer time-intervals than 10 minutes is increasing. Before deciding on the system to be adopted, proposals were asked for, and finally six systems were selected for trial, each being allocated a section of the line between Paris and Granville. Diagrams are given of the portions of the line occupied by each of these systems, two of which are automatic and the remainder semi-automatic. All are to be worked electrically. The conditions required are detailed, and there are full descriptions given, with illustrations of all the apparatus required for each system.

H. R. S.

Saint-Lazare Underground Railway-Station, Paris.

L. FOURNIER.

(La Nature, Paris, 1914, Premier Semestre, pp. 103-106.)

The steps taken in Paris to provide for increase in traffic on the Western Railway are described, and it is shown that the annual number of passengers has increased from 28 to 65 millions in

25 years. On certain race-days provision has to be made for 250,000 passengers per day. Until 1910, owing to constriction at Batignolles, there were only six lines of rails giving access to the terminal station. To the three existing tunnels a fourth was added, and it then became possible to make a distinction between main line and local traffic. It being impossible to widen further the line without expensive purchases of property, the State decided to construct an underground station for the lines to Auteuil and Saint Germain-en-Laye, now being electrified. The subterranean station will comprise eight lines of rails, involving the construction of four new lines through the Batignolles approach. The upper station of Saint-Lazare will have twenty-four lines of rails, in lieu of twenty-seven at present, and eight lines will be provided in the lower station. The narrows at Batignolles will contain ten lines at the high level and four at the low level. The decreased number of lines in the upper station is rendered necessary by a new system for the handling of luggage. The former tunnel at Batignolles, which will be demolished for a length of 362 yards, has several curious features, as it not only supports, under the boulevard above it, the Paris Metropolitan Railway, No. 2, but is crossed by two streets and is partly covered by buildings, now being removed that the new approach lines may be uncovered. The streets will be taken across the site of the actual tunnel by road-bridges. These bridges will have to be built while the trains are running constantly on the Metropolitan Railway. The main dimensions of the new station are a width of 246 feet by a length of 656 feet. It will thus be less than half the width of the station on the upper level, and it is stipulated that as small a space as possible shall intervene between the two stations. The lower one will take the form of four parallel tunnels, separated by walls pierced with openings. The difference of rail-level in the two stations will be about 32 feet, and, as the present station is about 16 feet above the street, it will be necessary to descend about the same distance to the new underground station for the local lines worked electrically. The general arrangements are explained by a sectional bird's-eye view.

G. R. R.

Towers for Rope-ways. Professors THIÉRY and CRETIN.

(Revue de Mécanique, Paris, 1913, vol. 33, pp. 505–550.)

This is one of a series of articles dealing with rope-ways in general, and a number of designs of wooden and steel towers are described and illustrated. The steel employed has generally a tenacity of 42 to 45 kilograms per square millimetre and an extension of 20 per cent. on 10 centimetres. The methods of calculating the dimensions of the various members of the towers are considered, several numerical examples being given. The exact calculations are extremely complicated, owing to the weight of the skips and the wind-effect on them being transmitted to the towers by the cables. Simplified approximate methods are therefore given, which are of ample accuracy for practical purposes. In allowing for wind-pressure it is explained that, after a certain wind-velocity, the rope-way must cease working. Two cases must, therefore, be considered; a maximum wind-pressure of 100 kilograms per square metre with the rope-way at work and of 270 kilograms with the rope-way not working. Two directions of wind are considered; in the longitude direction, the wind acting on the skips has considerable effect on the cable-tension; but it is the transverse direction which generally gives the greatest stresses in the towers. Methods of determining the stresses in the towers are given, together with numerical examples.

H. R. S.

Problems Involved in Driving Long and Deeply-Overlaid Tunnels.

D. LAUCHLIN.

(Engineering Record, New York, 1913, vol. 68, pp. 510-512.)

This is a general article on the influence of size and length of bore on progress and cost, driving methods, ventilation and refrigeration, ground-pressure, and lining in tunnelling. It gives cross and longitudinal sections of several important tunnels, with the different modes of dealing with their several difficulties, including the opinions on the subject of a member of the contracting firm for the Simplon tunnel, in favour of twin, as against double-track lines, and parallel rather than superimposed headings. The whole question of top and bottom headings is discussed. Mont Cenis and St. Gothard are quoted as costly examples of the former system, while the latter was or is being carried out on the Simplon, Lötschberg, Ricken, Granges, Arthur Pass, Tauern, Hauenstein, Karawanken, Wockein, Mont d'Or, Weissenstein and Wasserfluh tunnels. Ventilation, air-cooling—as exemplified at the Simplon, where the temperature reached 132°—ground-pressure and lining, are dealt with successively. There are two Tables, one giving costs and the other statistics regarding six prominent tunnels, more especially in reference to temperature and ventilation.

C. O. B.

Mont d'Or Tunnel. MAUGUIN.

(Revue Générale des Chemins de Fer, Paris, 1914, vol. 37, pp. 3-16.)

The Author, who is a constructional engineer in the service of the Paris–Lyon–Méditerranée Railway Company, describes the tunnel now being constructed on the Frasne-Vallorbe line, which will shorten the route to the Simplon. The tunnel lies between the stations of Longuevilles–Rochejean and Vallorbe, and is 3·9 miles in length, through the Mont d'Or, with one end in France and the other in Switzerland. The width inside at rail-level is 26·2 feet, the height from the rails to the soffit of the arch 20 feet, and a central drainage-channel is provided 19·7 inches by 19·7 inches, which is expected to be ample, as the difference in level between the two ends of the tunnel is 295 feet, and the gradient 1·3 per cent. descending to Switzerland. Diagrams show the method of procedure by forming an advance heading, then timbering it and opening a second heading under the soffit; then widening the latter and getting the arch in, and finally building the side walls and the road-bed. The distance from the finished work to the end of the heading was usually about 0·72 mile. At first the boring was done by hand, but afterwards about fifty Meyer pneumatic hammers, each weighing 33 lbs., were employed and gave satisfaction. All transport is effected by means of compressed-air locomotives, of which seven are in use, and 140 wagons. Considerable trouble was experienced with water, and a masonry wall had to be built across the tunnel temporarily to keep back the inundation, while means were taken to deal with it, and at one point near the middle of the tunnel a temporary heading had to be formed parallel to the main tunnel and at a distance of 65·6 feet, to pass round the springs and drain the tunnel itself. The Author gives a description of the plant installed at the two ends of the tunnel to provide compressed-air, electricity and power.

E. R. D.

Steam Drying-Cylinders. BELLANGER.

(Annales des Mines, Paris, 1913, vol. 4, pp. 425–443.)

The plant of a textile-factory includes a large number of steam drying-cylinders. The Author states that in the works in the neighbourhood of Lille alone there are more than 2,000 in use. In consequence of recent fatal accidents from explosion the construction of these cylinders has been made the subject of inquiry. They are practically all of one type. The body, usually 30 inches long and 27 inches in diameter, is of copper $\frac{1}{8}$ to $\frac{3}{16}$ inch thick, the ends being of $1\frac{1}{4}$-inch cast-iron. These "heads" have a diameter equal to the inside diameter of the copper cylinder, their outer edge being slightly chamfered. When these heads are in place in the course of construction, the copper extends a little beyond them. An iron hoop, about $1\frac{3}{16}$ inch by $\frac{7}{8}$ inch in section, having, when cold, an inside diameter equal to the inside diameter of the cylinder, is heated to redness and shrunk on. The projecting portion of the copper is then hammered to fill the chamfer and also to form an overlapping flange. Experience has shown this to be a sufficiently strong connection. Accidents have happened with cylinders from which one head had been removed and replaced to shorten them. Experiments made in the course of the inquiry show that the same security cannot be obtained without re-forging the hoop to restore its original dimensions and elasticity. This is the practical lesson to which the investigations have led, and it is not without interest to the makers of such cylinders. It is recommended as further security that a drain-cock be provided to discharge the condensation-water, and that a safety-valve be placed on the inlet steam-pipe to guard against excessive pressure.

G. G. A.

Brick-lined Concrete Chimney-Stack. T. B. Swift.

(Engineering and Mining Journal, New York, 1913, vol. 96, pp. 978-979.)

The Mountain Copper Company at Martinez, California, has recently replaced a wind-damaged steel chimney-stack by one of reinforced concrete lined with bricks. The new chimney is 223 feet in height. The foundation, which is octagonal, is 35 feet in diameter and is sunk 5 feet 6 inches. The structure is heavily reinforced by two mats of twisted steel. The vertical members of the reinforcement of the stack are embedded in the foundation, every second bar being bent under the lower mat. Around and tied to these vertical bars is a heavy woven-wire fabric. The design is calculated to withstand a wind-pressure of 125 miles an hour. The concrete wall is 15 inches thick at the bottom and 5 inches at the top, giving outside diameters respectively of 19 feet 4 inches and 13 feet 10 inches. This is a taper of 3 inches in 10 feet. The lining, 12 feet in diameter inside, 8½ inches thick for 140 feet, and 4 inches thick for the remainder, is of hard-burned red bricks. This barrel is strengthened by six 185-foot pilasters built into it and clearing the concrete by about 1 inch. The bricks are laid in an acid-proof cement composed of amorphous silica and finely-ground quartzite sand, tempered with a dilute silicate-of-soda solution. This cement has been found to be proof against the sulphatizing action of furnace-gases. It sets quickly and completely, and makes a strong bond. Steel forms were used for pouring in the cement. These were raised by chain-blocks supported from scaffold timbers run up on the inside of the stack, so that the green concrete had only its own weight to bear. The forms made a section 5 feet in height, and after the first few days one section was poured daily. The mixture consisted of Portland cement, sand and furnace-slag, crushed to about 1-inch ring size, in the proportions of 1 : 2½ : 3. An illustration shows the reinforcement.

G. G. A.

Pressure on Stop-Doors in Coal-Dust Explosions.

Dr. Czaplinski and — Jicinsky.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, Vienna, 1913, pp. 609–611, 623–628, and 643–647.)

The Authors published in 1912 a report of experiments undertaken at the testing-station in the Rossitz coal-mining district, for the purpose of ascertaining the resisting power of stop-doors for arresting the progress of the flame in a dust-explosion. The experiments were continued far into the year 1913, and their most important results are set out in these articles. One object in view was to obtain, by direct measurement, the pressures set up, and to this end a special form of indicator, of which illustrations are given, was designed. The highest pressure registered by this instrument was 1·4 atmosphere. A large number of experiments showed that the maximum pressure, gradually reached, occurs about 60 yards from the point of origin of the explosion. Beyond this the pressure drops slowly. At 90 yards it was found to be 0·8 atmosphere, and at 150 yards 0·25 atmosphere. In no instance did it exceed these amounts. Indicator-diagrams show the rapid rise and slow fall of the pressure set up by these dust-explosions. Acting on the knowledge thus obtained, doors were constructed of 3-inch pine planks free from sap. These doors, 5 feet 7 inches in height and 3 feet in breadth, were covered on each side by 2-millimetre sheet-iron fixed by screws thickly placed. Previous experiments had shown that without the iron, these doors were broken and torn away by the force of the explosion. Thus armoured, however, they stood the shock with very little damage. An over-lap of 2 inches was allowed on the posts, lintels and sill, which were embedded in the walls, roof and floor. Illustrations and Tables of results are given.

G. G. A.

Self-Regulating Compressed-Air Hoist. E. Leroyer.

(Bulletin de la Société de l'Industrie Minérale, Saint Étienne, 1913, vol. 4, pp. 583–605.)

The Author considers the self-regulating compressed-air winch, or hoist, as a new solution of an old problem of frequent occurrence in mining. It is a machine which may be used either as a hoist for raising or as a brake for lowering a loaded skip or cage in a shaft. As a hoist, it possesses the advantage of working expansively, thereby effecting a saving in the working cost; while, when acting as a controlling power in lowering the cage, it compresses air, forcing it into the conducting-pipes of the system. Thus the descending load is made to supply a portion of the power required for hoisting. Its efficiency as a brake makes it possible for the descent to be made at a high speed. A winch of this character has recently been installed at one of the mines at Dourges, fulfilling, the Author states, the conditions of an easy regulation of speed and freedom from heating while compressing. Moreover, it is a simple and strong machine, suitable for the rough work of mining. It is set over a shaft 11 feet in diameter and 270 feet deep, connecting two levels in the mine, and controls cages carrying two mine-tubs. It rests on two iron girders built into the shaft-wall. The cylinders, two in number, are oscillating and double-acting, and are connected directly to the drum-shaft. The direct connection was chosen for a high speed when working as a brake with a descending load, and also to avoid the noise of gearing. The whole occupies but little space. It can be changed in a moment from hoist to brake. In practice, an average speed of one winding from the depth of 270 feet in 20 seconds is reached; but this might be safely increased to 17 seconds. This gives a mean speed in the shaft of 17 feet per second. With three men above and two below, 186 tubs are dealt with per hour. The recuperation of compressed-air by the descending load is equal to the work of a compressor drawing in 1·8 cubic metre per minute. A noteworthy feature is that the compression is effected without appreciable heating. The economical results are said to be very satisfactory. This form of hoist is particularly suitable for inclined planes. The article is illustrated.

G. G. A.

Development of Electric Mine-Locomotives.

(Engineering and Mining Journal, New York, 1914, vol. 97, p. 22.)

Experience with electric mine-locomotives is constantly leading to the use of more powerful units. The largest yet built are the two recently installed at the Charleroi Mine of the Carnegie Coal Company in Pennsylvania. Each of these, which are of the Baldwin-Westinghouse type, weighs 30 tons, and is specified to be capable of hauling a train of 100 trucks of 3 tons capacity. The length of the haul is about 2 miles and the gradient is largely against the load. The ordinary 15- to 25-ton locomotives would not be sufficiently powerful to deal with the present output. These new locomotives possess novel features. Each consists of two independent units which can be separated, when desired, and used as 15-ton locomotives. They are of "bar-steel" construction, i.e., the frames, instead of being built up of plates, are formed of a grid of steel bars of heavy cross-section. The open spaces in these frames give ready access for inspecting and adjusting, and provide good ventilation for the electrical apparatus. Air-brakes are used, the compressor and main reservoir being on the leading unit. The trailing unit carries an auxiliary reservoir, but each is also provided with a hand-brake. The controller for the tandem is of the individual blow-out type, and controls all the four motors at once. When used as separate locomotives, the four-motor controller controls the two motors of its unit without change in connection, while the other unit has its own two-motor controller. A photographic illustration is given.

G. G. A.

Belgian Practice in Underground Haulage. F. Defize.

(Revue Universelle des Mines et de la Métallurgie, Liége, 1913, vol. 4, pp. 137-168.)

The Author, dealing with the question of underground haulage, describes the best current practice in the Liége mining district. The minimum permissible dimensions for a single tram-line are: width on floor 1·7 metre, width at the cap 1·4 metre, and height 2 metres. These dimensions are usually somewhat exceeded. Great care is exercised, by means of daily inspection, to keep the roads in sound condition. The rails in common use are of the Vignoles type, and weigh at least 12 kilograms per metre. In some mines rails of 14 kilograms are preferred. These are laid on oak sleepers. The gauge generally adopted is 510 millimetres. The rails, as well as other portions of the roadway, are inspected daily; for derailments have serious consequences when a locomotive is drawing a train of tubs. Often the driver is unaware of the mishap till much damage has been done both to the line and to the rolling-stock. The conditions and state of the latter, as to wheels and axles, are matters of great importance to the cost of haulage. The coefficient of traction should never exceed 10 kilograms per ton on a level road. It may be made as low as 5 kilograms. The weight of an empty tub averages about 300 kilograms, and the useful load 525 kilograms. Allowing a tractive force of 10 kilograms per ton, a maximum where the conditions of haulage are satisfactory, a locomotive capable of developing 8 to 10 HP. and weighing 5 tons can deal easily with trains of 30 to 35 tubs. The petrol locomotive appears to be winning the first place in the non-fiery mines of Belgium. Its chief merit is independent running. Several diagrams are given.

G. G. A.

Synchronous Motors for Air-Compression.

(Engineering and Mining Journal, New York, 1913, vol. 96, p. 930.)

A new feature in air-compressing practice is the use of the synchronous motor. The latest design of this form of motor being self-starting and self-synchronizing, an objection to the old type, which required an auxiliary device, is removed. Compared with the other forms of drive for large compressors, this improved type of motor offers many advantages. Being well adapted to direct connection, it leads to simplicity in the installation and thereby to reduced cost. Moreover it requires less floor-space. These motors can be arranged to raise the power-factor of the whole circuit by giving them excess capacity and using them as synchronous condensers. A typical example may be seen at the Wickwire Mining Company, Iron River, Michigan, where two compressors are each driven by a self-starting synchronous motor. One of these, driven by a 220-HP. motor, delivers 1,352 cubic feet of free air per minute; the other, driven by a 175-HP. motor, delivers 995 cubic feet. The former makes 200, the latter 225 revolutions a minute. A voltage of 6,600 is stepped down to 2,200 volts for these motors. Notable features of these motors are simplicity of construction and great strength. The stator is supported by a heavy cast-iron frame, and the coils, which are form-wound, are arranged so as to be easily removed and replaced. The rotor consists of a cast-iron "spider," which carries the field-poles. Each field-coil can be easily removed and the windings are arranged to afford good ventilation. A remarkable feature of the rotor is the squirrel-cage winding which encircles the field-poles. This winding makes the motor self-starting and prevents "hunting" or surging.

G. G. A.

Drill-Hole Pumping. R. H. HEAP.

(Engineering and Mining Journal, New York, 1913, vol. 96, pp. 1209-1210.)

A notable feature in mining in the Miami district in Oklahoma is the draining of ore-bearing ground by means of drill-holes and centrifugal pumps. The idea is not new, but it had not before been applied on so large a scale. In the case dealt with by the Author, the pumping was to be from a depth 239 feet below surface. A suitable place in the drift having been selected, a $6\frac{1}{4}$-inch bore-hole was put down from surface, passing through the drift at that spot, and continuing down to a depth of 60 feet below the drift-floor. This lower portion of the hole was then reamed out with a 15-inch bit of 1,400 lbs. weight. To form a chamber at the bottom of this hole, and at two points above, 20 feet apart, two charges of dynamite, consisting one of 35, the other of 57 cartridges, were exploded. After these shots the big bit was lowered and the loose rock broken up and cleared out. As a precaution, the top 12 feet of the hole were lined with 12-inch pipe, perforated with 1-inch holes, and on this the 8-inch check-valve of the 6-inch com[illegible]n type centrifugal pump rested. The drill-hole to surface was lined with $5\frac{5}{8}$-inch pipe through shale to a depth of 170 feet. Steam was led down this hole to the engine through a 3-inch line, reduced to 2 inches in the drift. The 3-inch pipe was adopted to give capacity for a second pump to be installed later. The maximum speed attainable with the 16-HP. engine was 730 revolutions a minute, at which speed the pump delivered 1,500 gallons a minute. As the suction-lift increased through the lowering of the water in the hole, the speed dropped to 620 revolutions. A more powerful engine was then put in, and a speed of 900 revolutions was reached, giving a discharge of 1,600 gallons. This volume decreased as the suction-lift increased, till the discharge became 1,350 gallons with a 20-foot lift, at which the pump is now working. The result in draining the ground has been so satisfactory that a second hole, 180 feet distant from the first, is being bored for a similar installation. An illustration is given.

G. G. A.

Air in Place of Water in Drilling. RALPH WILCOX.

(Engineering and Mining Journal, New York, 1913, vol. 96, pp. 973–974.)

The Author gives some novel experiences in diamond-drilling. In some kinds of friable schist boring is made difficult and costly by the caving-in of the sides of the bore-hole, which is largely due to the water forced into the hole. Experiments showed that it is practicable to substitute air for the water by forcing it down the hollow rotating rods. The air passes round the boring-crown, thereby cooling it, and ascends on the outside of the rods, carrying up the borings as satisfactorily as the water had done. More than 6 months' experience with this method in the copper-bearing schists at Miami, in Arizona, have proved its value in practice, the difficulties of boring in that class of rock having been reduced fully 75 per cent. thereby. It was found unnecessary to reduce the speed of rotation of the bit, the cooling action of the expanding air being sufficient to prevent a more rapid wear of the diamonds. The maximum air-consumption was 83 cubic feet of free air per minute, while the least with which the work could be carried on was 23 cubic feet. The average was 47 cubic feet at 75 lbs. pressure. Nothing is known yet as to what the limit of depth may be, the borings hitherto not having exceeded 300 feet. Apart from its advantages in friable rock, there is the possibility of boring in localities where a scarcity of water would otherwise prevent a boring from being made. Drilling in such regions could be accomplished by the use of a portable compressor driven by a gasoline-engine.

G. G. A.

Portable Electric Safety-Lamps. E. SCHORRIG.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, Vienna, 1913, pp. 748–750.)

The Author gives general practical information as to the use of portable electric safety-lamps. Of the 304 fire-damp explosions which occurred in Prussian coal-mines in the last 10 years, 187 were caused by safety-lamps. The benzine-lamp, though in some respects safer than the oil-lamp, has not proved an unqualified success. Hence more attention has been given of late to the portable electric lamp. Two circumstances have militated against its general adoption; the older forms were not absolutely safe, and they gave no indication of the presence of fire-damp. The former objection has been entirely removed, and the latter is in a fair way of being overcome. There are three approved types in common use in the coal-mines of Germany, the Varta lamp, the Ceag lamp and the Friemann-Wolf lamp. The two former are fitted with the ordinary lead accumulators; the last, with the lead accumulators, has the alkali element characteristic of the Edison type. In practice the number of lamps returned to the lamp-room extinguished or burning dimly has in no instance exceeded 1·25 per cent.—a much better result than the benzine-lamp can show. At the Frisch-Glück and Desdemona nitrate works, the percentage is as low as 0·5 to 0·7. The practice of German mines is in favour of the ordinary lead accumulator. Of these the positive electrode lasts about 400 hours of light-giving activity, and the negative about half that time. The filament, usually of the Osram-metal kind, lasts about 800 hours. For closing the lamp, the bayonet-joint is preferred. The cost, when every source of expense is taken account of, works out at about 1*d*. per lamp per shift, where 1,000 lamps are in use. With a larger number, the total costs would be materially reduced. These results of actual practice show great progress in the last 2 or 3 years; but it must not be forgotten that safety depends in a large measure on the handling of the lamps in the lamp-room.

G. G. A.

Safe Shot-Firing in Coal-Mines. CABOLET.

(Glückauf, Essen, 1914, pp. 26-28.)

A newly-devised method of making shot-firing safe in dusty coal-seams has been adopted at the Consolidation Mines at Gelsenkirchen. The principle involved is to fill the atmosphere in the immediate neighbourhood of a shot with a fine water-spray, not only before the shot is fired, but during the time of explosion and for a short time after. This is effected, where water-spraying is in use, by means of a special apparatus contained in a small box, which is hung by chains to the roof at a distance of 5 to 10 yards from the face of work. A noteworthy feature of the apparatus is that it automatically fires the shot at the right moment. When in position, it is connected to the water-pipe which conveys the water under pressure to the working places. All being ready, and the blasters under cover, an electric current is sent through the apparatus, in which a powerful electro-magnet is made to open a valve and the spray is set in action. When the air and the coal-surfaces have been sufficiently moistened, a piston, which has been slowly moving forward under the pressure of the water, closes the circuit through the fuse, and a portion of the current is shunted to fire the shot. The time allowed between the beginning of the sprinkling and the explosion, which may be regulated at will, varies, according to the conditions of the place, between 5 and 20 seconds. The spray continues as long as the current is allowed to flow through the apparatus. Thus the hot gases from the shot are thrown into a water-laden atmosphere, and the continuation of the jet further cools them, while at the same time moistening the fresh dust made. Apart from safety against dust-explosion thereby afforded, a practical advantage of this method lies in the fact that much of the smoke is thrown down by the spray, and the working-place is quickly cleared. Six of these machines are in use at the Consolidation Mines. Their handling is said to be very simple, and to take little time. The article is illustrated.

G. G. A.

Portable Testing- and Shot-Firing Apparatus.

O. Dobbelstein.

(Glückauf, Essen, 1914, pp. 134-136.)

This apparatus, which is in use in a number of mines in Germany, is a handy portable contrivance for testing an electric circuit, and for firing a blasting shot. To avoid the annoyance and danger of a missfire, many firemen are willing to take the slight extra trouble of testing the circuit before attempting to explode the charge. The "Combinator" consists of two strong sheet-iron boxes fixed one upon the other. The lower box contains the battery furnishing the current; the upper box holds the galvanometer, resistances and switches. They are insulated from each other by a partition of wood and other insulating material. The battery is composed of dry elements, now much used for shot-firing, one cell being separated from the rest to be used for testing only. When a blast is ready to be fired, the cable-wires are attached to the Combinator, and the key inserted in the resistance-measuring circuit. The galvanometer now shows the resistance of the circuit in ohms. The key is then transferred to another portion of the board and the switch turned to a certain point. This tests the fuse by sending 0·006 ampere through it, when all is in order. If the result is satisfactory the switch is turned to another point, and the blast is fired. The battery gives an electromotive force of 4½ volts. These dry elements show but little weakening after 6 months' daily work. The apparatus is fully described and illustrated.

G. G. A.

Testing of Coal for Purchase. J. M. Goldman.

(Journal of the Association of Engineering Societies, St. Louis, Mo., 1914, vol. 57, pp. 35–54.)

This Paper deals with the methods of testing Illinois bituminous coal purchased for steaming purposes by the United States Engineer Office in St. Louis. The sampling of coals in the mines, the heating value of the various coals, preparation of samples, the laboratory plans for testing, and a method of comparing grades of coal by formula.on the basis of calorific value are described. There is also a summary of geological conditions of the deposits. Samples can be taken in the mine by removing a strip 4 to 6 inches in width from the seam. For sampling in bulk or barges, pipes about 3 inches in diameter and 6 feet long are inserted in the coal. The laboratory tests consist of ascertaining the amount of ash and the calorific value, a bomb-calorimeter being used. A formula is derived from which the deduction in price to be made can be ascertained should the coal prove to be unduly high in ash or low in heating-value. The estimates sent in can be compared in the same way, so that the maximum heating-value may be obtained per unit-price.

R. S. B.

Winding with Counter-Weight in Shaft-Sinking.

(Glückauf, Essen, 1914, p. 75.)

The system of using a counter-weight in raising the excavated material in shaft-sinking when the shaft is of no great depth, as, for example, a winze connecting two levels, has recently been adopted, with exceptionally satisfactory results, at the mines of the Constantin-der-Grosse Company in the Ruhr district. The winding-rope, long enough to reach to the bottom of the completed shaft, was passed over the winch-sheave at surface, then led under the pulley of the counter-weight, and gripped in a support on the surface timbering, the end portion, not needed at the outset, being wound on a reel to be let out as required. The counter-weight being thus suspended on a double rope only half its weight was thrown on the winch, and it always hung high above the face of work, the bottom of the sinking, quite clear of the workmen. This proved to be a very helpful arrangement, as it left the working place free of encumbrance. When half the depth was reached, all the rope had been given out from the reel, and thereafter the counter-weight rose higher and higher in the shaft as the sinking progressed. The other end of the rope was of course attached to the sinking bucket, which, to occupy less space, was of small diameter and considerable depth. An illustration shows the application of this system to a sinking at the Constantin-der-Grosse Company's mines.

G. G. A.

Production of Potassium-Salts in Alsace. GRANDMOUGIN.

(La Technique Moderne, Paris, 1914, vol. 8, pp. 49–54.)

As the result of boring for coal and oil in the neighbourhood of Mülhausen, two seams of salt, one of an average thickness of 1·64 metre, and the other, just below, of 4·15 metres, were discovered. Subsequent borings determined the extent of the deposits, and showed that they were at depths of 200 to 700 metres, and were estimated to contain 300,000,000 tons of salt, consisting principally of potassium-chloride and sodium-chloride, forming a mineral known as sylvinite. The sinking of the shaft for the Amelie pit is described; when passing through the gravels the freezing process was adopted. Below the gravels little water was encountered, except at the 200-metre level, where there was a considerable inflow. The water-tightness of these shafts is of vital importance, and disaster to the mine might easily ensue if there were any filtration. Descriptions and small-scale drawings of the apparatus at the pit-head are given. A large proportion of the salt raised is merely crushed, but a small amount is treated by a special process to produce 98 per cent. of potassium chloride, which depends on the practical equality of solubility of sodium-chloride in hot and cold water and the much greater solubility of potassium-chloride in hot water.

H. R. S.

Transport and Handling of Iron Ores in Tunis. L. FELIX.

(Revue Générale des Chemins de Fer, Paris, 1913, vol. 36, pp. 243-255.)

The Bôna–Guelma Railway Company makes a speciality of the transport of heavy goods, especially iron ores, on a metre-gauge line. The locomotives are of the Mallet type, with two sets of six wheels coupled, and weighing 60 tons in working order; but the wagons are of a special type made by the Société Dyle et Bacalan. Each wagon is carried by two bogies, and is 36·27 feet over buffers, with a tare of 13·64 tons and a carrying capacity of 30 tons, and is provided with a screw-brake acting on all the eight wheels and worked from a small cabin above one end of the truck. The frame is built entirely of steel and furnished with central draw-bar buffers. The body is also of steel, with the exception of the brakesman's cabin, which is of wood, the bottom of the wagon is an inverted V to facilitate discharge, and the side doors are hinged above and swing outwards. There are five doors at each side, and they are opened by means of levers at the end which actuate a longitudinal shaft at each side of the wagon, and it is possible to open one or more of the doors without opening all. Special apparatus has also been provided for charging the wagons at Djebel Djerissa, whence 40,000 tons of ore are transported monthly. At the mine the ore passes down an inclined plane to a large double hopper having a capacity of 1,000 tons, and from it the wagons are filled by simple controlling-gear. The empty train is taken past the hopper, and the wagons are then allowed to descend one by one on an incline of 7 per 1,000 to be filled. Three men suffice for the loading of a train. At the docks the shipment is more difficult, and there the wagons are discharged on to a Robins travelling-band adjustable over the hatchways of the vessels.

E. R. D.

Chilian Mills. HERBERT A. MEGRAN.

(Engineering and Mining Journal, New York, 1913, vol. 96, pp. 822, 823.)

The Author gives practical information as to the design and efficiency of Chilian mills, now much used in mining. The Chilian mill is largely an adaptation of the ordinary edge-runner to ore-crushing. Two types of these are in use, known respectively as high-speed and low-speed machines. The high-speed mills, more often used than the low-speed type, have small runners, the diameter of the pan being 4 to 6 feet. The runners are 2 to 3 feet in diameter and 4 to 6 inches on the face. These make about 34 revolutions a minute. The low-speed mills have pans of 6 to 10 feet diameter, and runners up to 7 or 8 feet, and make only about 14 revolutions a minute. These runners are broad on the face, as much as 20 inches being reached for some classes of work. The high-speed mills are often used for re-grinding, following rolls, or breakers, and even stamps. They show the highest efficiency when working on material somewhat larger than ¼ inch diameter. Stuff coming from rolls ¼ to ½ inch in diameter is very suitable. There are many examples of crushing with rolls followed by Chilian mills. A 6-foot mill, making 34 revolutions a minute, and crushing through a 30-mesh wire slot screen, is capable of dealing with 125 tons of ore in 24 hours. The low-speed mill is not suitable for re-grinding work. It does its best work on coarse material passed once through the mill, using with it a large excess of water. This type is adapted to produce a large quantity of very fine material. One passage through the mill is sufficient to grind a very high percentage of the ore to such a degree of fineness that it will pass through a 200-mesh screen. Tables show the work and efficiency of these two types of mills.

G. G. A.

Separation of Pyrites from Blende. Pierre André.

(Bulletin de la Société de l'Industrie Minérale, Saint Etienne, 1913, vol. 4, pp. 383–400.)

The concentration of zinc and lead ores containing iron in the form of sulphide (pyrites) has hitherto been a work of great difficulty, by reason, chiefly, of the practical equality of the specific gravity of blende and pyrites. But the progress of electric science has made it economically possible to apply magnetic separation to these ores. By this means, and through a careful roasting to give to the different constituents of the ore the requisite magnetic permeability, and a suitable speed of the carrier-bands, the difficulties have been overcome at the Sakiet-Sidi-Youssef mines in North Africa. The importance of speed is shown by experimental results, from which it appears that blende begins to be acted upon by the magnetic force when moving at 40 metres a minute, and attains its maximum sensibility to that force when the speed of the carrier is 30 metres a minute, the exciting energy being kept constant at 1,000 watts.

The ore treated at these mines is an intimate mixture of the sulphides of lead, zinc and iron. The proportion of zinc varies between 10 and 16 per cent., of lead between 5 and 9 per cent., and of iron between 6 and 9 per cent. This ore is first crushed to pass through a 3·25-millimetre mesh. A subsequent crushing between rollers gives two classes or grades of 1 millimetre and 1 to 2 millimetres respectively. The magnetic portion of the separator consists of a lower electro-magnet, having its poles turned upwards, and an upper similar magnet whose poles are turned downwards. Running between these, and sliding upon the upturned poles of the lower magnet, are two india-rubber carrier bands, 350 millimetres wide, inclined at an angle of 12°. One of these conveys the finer, the other the coarser material. One of the poles serves for one of the bands, the other for the second band. The two magnets give two magnetic fields for each band. These are the main features of this new design of separator. The works at Sakiet deal with 40 tons in 24 hours, an output requiring the services of only six men and a boy.

G. G. A.

Heat-Treatment of Metals in the Workshop—Case-Hardening.

F. Robin.

(Révue de Mécanique, Paris, 1913, vol. 33, pp. 409–458.)

After a short history and theoretical exposition of the process of case-hardening of steel, it is pointed out that, although for research purposes the determination of the carbon-content of each thin layer is necessary, for practical purposes a micrograph-section should be taken, and with this object, the Author has produced a special workshop outfit by means of which micrograph-sections can be obtained up to 150 diameters. Various typical micrographs are given, with corresponding curves showing the percentage of carbon at various depths. There is detailed information of the composition and use of the numerous case-hardening substances on the market, solid, liquid and gaseous, together with the effect of temperature and the duration of process on the depth of the case-hardening. Although temperature is of extreme importance, it is only when case-hardening is effected by means of gas that it can be measured; generally it must be estimated. The case-hardening of special steels is considered, and it is stated that chromium, tungsten and molibdenum assist cementation, whereas nickel and vanadium retard it. The actual workshop-process is described in detail, and the numerous defects which may occur are stated, with the means of detecting them.

H. R. S.

Steel Converter Design. HUBERT HERMANNS.

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1914, vol. 58, pp. 46–53.)

In the more recent designs the cylindrical type is rapidly replacing the pear-shaped converter, mainly on account of the increased output required in modern plant. Cylindrical converters of 150 tons, 400 tons, 750 tons and 1,200 tons capacity are described. Electrically-operated tilting-gear is replacing the less convenient hydraulic arrangements formerly used, and this has been rendered possible mainly by the introduction of simplified roller-bearings and increasingly efficient gearing. The latest phase in the development of large converters is the introduction of the shallow, flat-hearth type, in which an increased rate of heating and pouring is possible. The article is illustrated.

C. J. G.

Recent Progress in Incrusting Metals and Applying Metallic Surfaces. P. NICOLARDOT.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1913, vol. 120, pp. 569–605.)

There are three methods by means of which it is possible to apply a metallic coating: by the employment of molten metal, by means of electrolysis, or by the use of pulverized metal on the Schoop system Processes of a really chemical nature are only employed in very special cases in the silvering of mirrors. To obtain perfect adhesion, it is necessary to roughen the surface to which the metal is applied, and the best mode of doing this is by the sand-blast, but in cleaning iron, nitric acid may in some cases be used in preference. An account follows of the use of baths of molten metal as, for instance, in applying tin and zinc, with the precautions to be observed. The subject of electrolysis is illustrated with photographs of the special apparatus for gilding, plating and deposition of nickel. Among new processes described is that of *sténogravure*, or engraving copper rollers by electrolysis. The Author also discusses some investigations he has made which tend to explain the results of electro-deposition. He attributes these results to a species of molecular bombardment, and he gives photographs to illustrate his theory. The invention of Mr. Schoop was due to his observation of the splash made on walls by leaden bullets, from which he conceived the idea of violently propelling metallic dust against the surface to be coated, so that the metal was reduced to a pasty, semi-fused consistency by the force of the impact. The various methods of employing this process, and the requisite apparatus for using molten metal filaments in lieu of dust, are illustrated and described. It is possible by this means to obtain metallic incrustations of great density, and the Author explains how he has been enabled to ascertain as also to vary the hardness of the Schoop deposits with different kinds of metals and to produce metallic powders and deposits.

G. R. R.

Electric Iron-Smelting at Hardanger, Norway.

GUSTAF ÖDQUIST.

(Teknisk Ukeblad, Christiania, 1914, pp. 2–8.)

This Paper deals with the probable causes of failure to work an electric iron-smelting installation on a commercially profitable basis. The Author describes the equipment, including the two furnaces, comparing them with other types used elsewhere. It is stated that, through faulty arrangement of transformers and electrical connections, the first furnace never received more than about two-thirds of the calculated energy, and this not being discovered for some time the poor results were attributed to other causes, such as the use of coke, inferior ore, etc. At the later period some of these faults were remedied. The second furnace worked satisfactorily in these respects at the higher voltages, and the fact that it produced only 1·87 ton of pig-iron per horse-power-year was due to other causes. The Author then enters in detail into the effect of coke as compared with charcoal, the quality of the ores used and gas-circulation. The gas-circulation had to be suspended in an endeavour to increase the power of furnace No. 1, although the coke-consumption was thereby increased from 336 to 385 kilograms per ton of pig. The ores used averaged about 50 per cent. of iron, and it was necessary to use considerable quantities of limestone, which was particularly disadvantageous where coke was used. The consumption of electrodes was heavy, as shown by a tabular comparative statement. The pig produced proved that an iron of good quality, free from impurities, could be manufactured by means of coke, but, unfortunately, the quality of the iron varied greatly, chiefly due to the design of the furnaces, which was unsuitable for the use of coke, the temperature at times being far from constant. The Paper not only sets forth the probable causes of failure, but gives comparisons with more successful installations and suggestions as to improvements in apparatus, materials and methods.

L. S. Z.

Hard Soldering with Tar-Oil Flame.

(Annalen für Gewerbe und Bauwesen, Berlin, 1913, vol. 73, pp. 141-142.)

It is customary to employ charcoal fires for soldering operations, because they produce no smoke, do not yield slag or sulphur, and render it possible to obtain large heated areas over which the solder can be maintained at a uniform temperature. Some of the disadvantages of this procedure are discussed, and it is shown that the flame of tar-oil gives out a great heat and can be easily regulated. After preliminary experiments and careful measurements, it has been found possible at the Berlin Railway Works to reduce the cost of brazing and soldering by 50 per cent., using tar-oil at 2·73*d.* per gallon and air at a pressure of 90 lbs. per square inch, costing to produce about 1*s.* 10·6*d.* per 1,000 cubic feet. This is substituted for the wood charcoal fires formerly employed in the coppersmiths' shops, and is used for the hard soldering of flanges, tubes, floats, copper-pipes and the bending of pipe-connections for brakes and similar work. Illustrations are given of the plant, which consists of an iron chest supported on four feet, lined with silica fire-lumps, so disposed as to form four heating-chambers, or pot-shaped vessels, of different sizes. These are surrounded with firebrick. At the base of these vessels jets are introduced for the tar-oil, which passes through apertures arranged in the lining. The burners for the compressed-air and oil, with flexible-tube connections, rest on angle-irons on the front of the furnace and can be moved to any required spot and clamped in position. The fire-lumps are such bad conductors of heat that, when white hot on one side, the hand may be placed on the other. For tubes and flanging operations there is a metal cover in the form of a half cylinder lined with firebrick to place over the pots and form small muffle-furnaces. Different modes of using the apparatus for special purposes are explained by a diagram. The burners in use can be employed with safety when the oil is supplied at a slight pressure.

G. R. R.

Clearing Wash-Water for Blast-Furnace Gas.

THEODOR STEEN.

(Stahl und Eisen, Düsseldorf, 1913, pp. 1945–1946.)

This is a further improvement, in the direction of simplicity and efficiency, in the methods of dealing with furnace-gas wash-water. The system described has been installed at the Phoenix Works at Horde, Westphalia, to deal with 100,000 cubic metres of gas per hour. A second installation of similar capacity is about to be made at works at Dortmund. One of the difficulties in dealing with the deposited mud lies in its tendency to cake and adhere to the surfaces on which it settles. In this system the floor of the settling-pond consists of a number of hopper-shaped receptacles with fairly steep sides. The water, with the dust from the gases, is made to flow slowly over these so that the mud is gradually deposited in them. When the mud has reached a certain height, and before it has begun to cake, the flow of water is stopped, and, after clearing sufficiently, is run off or pumped out till its level has come down near to the surface of the mud. As the furnaces are in operation day and night, two settling-ponds are provided for continuous work. To remove the deposit, there is a set of pipes running over the receptacles with branches dipping to near the bottom of each. These pipes are in communication with a closed iron vessel to which an air-compressor, driven by an electro-motor, is connected. The compressor, by an automatic arrangement, alternately sucks the mud into the vessel and forces it out through a pipe at the bottom. At the Phoenix Works it is conveyed away by this pipe a distance of 800 yards and raised to a height of 150 feet above the discharge-valve of the vessel. These operations are continued till the receptacles in the settling-pond are emptied. Only one man is required to attend to this work. The total cost of transporting the mud is a little under 2½*d.* a ton. As the water drawn off is sufficiently clear to be used over again the actual consumption is very small.

G. G. A.

New Process of Cleaning Producer-Gas. H. F. SMITH.

(Journal of the American Society of Mechanical Engineers, New York, 1913,
vol. 35, pp. 1599-1608.)

A new cleaning-apparatus is described, the object of which is to clean gas more effectively than by the usual process. The gas is blown through a porous diaphragm, which has the property of coagulating the very finely divided tar-particles, which can then be removed from the gas by an ordinary separator. This diaphragm is made of ordinary glass-wool (not slag-wool), which is retained between two metal screens. The thickness of the diaphragm is about ¼ inch, and each square inch can deal with about 400 cubic feet of gas per hour. No tar is retained on the diaphragm. A difference of pressure across the diaphragm of about 2½ to 4 lbs. per square inch is needed, and is obtained by means of a blower. The reason of the action of the diaphragm is somewhat obscure, but it is suggested that it is in some way due to the electricity produced by the friction of the gas on the spun glass. Experiments are described which appear to favour this view. A description and illustration of a cleaner of this nature, capable of dealing with the producer-gas of a 1,000-HP. plant, are given.

H. R. S.

Extraction of Carbon-Bisulphide from Coal-Gas.

C. C. Carpenter, D.Sc.

(Proceedings of the Société Technique de l'Industrie du Gaz en France, Toulouse, 1913. pp. 245-250.)

The first portion of the Paper is mainly historical and refers to attempts made by early investigators to extract carbon-bisulphide by passing coal-gas over a heated contact or catalytic mass. As a result of an organized laboratory investigation and a series of large-scale experiments, a trial-installation, capable of dealing with 2 million cubic feet of gas per day, was erected in 1911 at the Old Kent Road works of the South Metropolitan Gas Company in London. The process consists of conducting coal-gas over a fire-clay material impregnated with reduced nickel, maintained at a temperature of 800° to 932° F. Before contact with the catalyst, the gas is preheated to a temperature approaching that at which the reaction takes place, and the employment of iron vessels as containers for the catalyst is thereby rendered possible. Carbon is precipitated on the catalyst as a result of the decomposition of carbon-bisulphide, and is removed by a process of slow combustion in situ, at intervals of about 30 days. A large installation, capable of purifying 10 million cubic feet per day, has been erected at the above works. This plant, which is divided into five units, is designed with one outside producer. The combustion-chambers are placed between the reaction-tubes containing the catalyst and the preheating tubes, and the volumes of heated gas to be passed in both directions are suitably regulated. Waste heat is recovered from the coal-gas leaving the catalyst by cross-current heat-interchangers. The average sulphur content of gas before catalytic treatment is 40·40 grains, and after treatment 7·8 grains per 100 cubic feet, a reduction of 80·7 per cent. The cost of operating the process, excluding charges for removing sulphuretted hydrogen produced in the reaction, is 0·37*d*. per 1,000 cubic feet of gas. Since the erection of this apparatus (3 months) 13·5 tons of sulphur, equivalent to 42 tons of sulphuric acid, were removed from the gas. The reaction takes place according to the equation

$$CS_2 + 2\,H_2 = 2\,H_2S + C,$$

but the quantity of carbon precipitated on the catalyst, in practice, exceeds that realized when operating with pure chemicals and probably arises from hydrocarbons of the gas. The illuminating and calorific powers of the gas are not diminished by this process.

E. V. E.

Coke-Oven Gas in Germany. Hache.

(Journal für Gasbeleuchtung, Munich, 1913, vol. 56, pp. 1032-1034.)

The practice of utilizing coke-oven gas for public use becomes of considerable importance in Germany, and the Author has collected information from the colliery districts of the Rhine and Westphalia as to the quantities of coke-oven gas supplied to neighbouring town-gasworks. The conditions regulating the supply are also quoted for the purpose of effecting the standardization of contracts. It is advisable that the coke-oven works should undertake the maintenance of the high-pressure gas-mains to the gasworks, and in twelve cases out of sixteen the main has been laid down by the suppliers. It is usual for the gas to be purified at the coke-oven works, and the stipulation is made that it should be technically free from tar and sulphuretted hydrogen, that the ammonia content should not exceed 0·86 grain per 100 cubic feet, and naphthalene 19 grains per 100 cubic feet. It is further required that the proportion by volume of carbon-dioxide and nitrogen should not exceed 2 and 3 per cent. respectively. As regards the calorific power of the gas supplied, it is agreed that the annual average should not be less than 550 B.Th.U. per cubic foot, whilst the minimum value should not fall below 530 B.Th.U. per cubic foot. Fluctuations are to be avoided, and a limit of 21 B.Th.U. per cubic foot is placed. Gas is delivered from the coke-oven works at a steady pressure sufficient to raise the holders of the gasworks, and is already supplied to certain large towns at the price of 8½*d.* per 1,000 cubic feet.

E. V. E.

Storage-Battery Control by Counter-Electromotive-Force Cells.

(Electrical World, New York, 1913, vol. 62, pp. 1267-1268.)

Counter-electromotive-force cells provide voltage-regulation for a 150-cell 5,750-ampere-hour standby storage-battery in use by the Union Electric Light and Power Co., St. Louis, Mo., remotely-controlled magnet-switches being used to short-circuit in succession the subtractive counter-cells, thus raising the effective terminal voltage of the whole battery. This battery does not float on the line, but is automatically thrown on to the system when needed by low-potential relays. Meanwhile the battery receives no preliminary voltage-adjustment except the cushioning action automatically interposed by the counter-cells. Compared with end-cell systems, this counter-cell method avoids excessive copper construction in the battery-room, eliminates expensive end-cell switches, and works all the active cells of the battery uniformly on both charge and discharge. The counter-cells are not kept charged, but acquire their voltage immediately after being put into circuit, and build up the difference in pressure. The battery and its connections and operation are described, and good results have been obtained without any trouble developing. By this arrangement the battery can be thrown on to the 220-volt system while its own terminal pressure is 60 to 70 volts above the bus-potential, without perceptible voltage-variation of current-flow.

P. T. S.

Instability of Electric Circuits. C. P. STEINMETZ.

(Proceedings of the American Institute of Electrical Engineers, New York, 1914, vol. 33, pp. 13–29.)

The importance of determining the laws of instability in electric circuits has, of recent years, received much attention, and the subject can be sub-divided as follows:—(1) The transients resulting from the readjustment of the stored energy to changed circuit conditions; (2) Unstable electric equilibrium, that is, the condition in which the effect of a cause increases the cause; (3) Permanent instability resulting from a combination of circuit-constants which cannot co-exist. The first type has been much studied, but generally, by considering that the "constants" of the circuit do not vary during the transient phenomenon, whereas, in reality, they do so. Such, for instance, is the change of inductance in circuits containing iron, or the change of resistance with frequency. The second type is illustrated by means of the speed-torque curves of an induction-motor for various impressed voltages, and the conditions of stability are investigated for a constant torque, for a torque varying directly and as the square of the speed. The third type is illustrated by means of a transmission-line, with two underground conductors, having a capacity against "ground." The "ground" is brought within striking distance of one of the conductors, and it is shown that under certain conditions, if one discharge takes place, the phenomenon becomes recurrent. The latter type is also illustrated by describing the hunting of synchronous machines.

H. R. S.

Reinforced Concrete Exposed to Electric Currents.

K. LUDOWSKY.

(Elektrotechnische Zeitschrift, Berlin, 1914, vol. 35, pp. 16-18 and 33-36.)

Numerous experiments are described made at the High School at Darmstadt, to determine the corrosion of steel embedded in concrete blocks, some 1 cement to 4 aggregate, and others 1 to 9. Curves show the electrical resistance during setting, and it was found to rise slowly at first and then more rapidly. In one case after 40 days the resistance had risen to 16,000 ohms. The effect on electrical resistance due to absorbed water is also shown. In one example it dropped from 2,000 ohms to a little over 200 ohms in 3 hours, and then remained constant. The blocks tested were exposed to an electric current, 210 to 220 volts at 60 cycles, and curves are given of the current, temperature and resistance. In one case, with concrete 1 to 9, the initial current was 0·12 ampere, dropping rapidly to 0·05 in 1 day, and to 0·01 at the end of 4 days, when cracks appeared. The temperature at first rose to 45° C., and at the end it had dropped to 25°. The resistance increased fairly regularly from 2,000 to 16,000 ohms, over the same period. To test the effect of high voltage, a small pillar of concrete, standing on a metal plate connected to earth, and containing a spirally-wound wire to represent armouring, was used. It supported a porcelain insulator, to which a wire was fixed carrying 60,000 volts. A condenser was thus formed and a difference of pressure of 300 volts was observed between the armouring and the earth. This gave rise to the idea that it might be dangerous to touch the concrete, but it was shown that in so doing, the current which would flow could only be 0·63 milliampere, whereas a current of 20 milliamperes is the limit of danger. The effect of a 200,000-volt discharge was also tried, and after a short time steam issued from the concrete, and it was found that a tubular path had been fused through the concrete.

H. R. S.

Electrolytic Wireless Detector. PAUL JEGOU.

(La Lumière Électrique, Paris, 1914, vol. 25, pp. 69–74.)

After explaining the principle of action of electrolytic wireless detectors, several different forms are illustrated and described, in some of which provision is made for interchangeable platinum points of fine wire. Originally merely a couple of cells were placed in the circuit, but in recent models the electromotive force is adjusted to the best value by means of a potentiometer. This "best" electromotive force is shown to be the counter electromotive force of the electrolytic cell. The platinum wire is generally arranged as the anode, in which case the counter electromotive force is somewhere over 2 volts. The Author, however, suggests that the platinum be made the kathode, and if the anode is of mercury-zinc, there is no counter electromotive force, in which case no electromotive force is needed in the circuit, and, of course, no cells or potentiometer, thus considerably simplifying the apparatus.

H. R. S.

Electrolytic Corrosion of Iron in Soils.[1] B. McCollum and Logan.

(Discussion.)

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 2291-2299.)

Mr. A. Maxwell pointed out that the range of the Author's experiments was 0·03 to 5 milliamperes per square centimetre, whereas, measurements which he had made with a Haber earthameter showed that the average current-density for areas between 100 and 600 square centimetres was 0·0005 to 0·04 milliampere per square centimetre. Mr. A. F. Gants, by computation, gave 0·002 to 0·03 milliampere as the density of current. In reply, Mr. B. McCollum said that a density of 0·005, if evenly distributed over a pipe, would not produce serious corrosion in 100 years, and although the average density of the current in the soil might be of that order, it would be concentrated at the pipe in spots, and therefore the range of the experiments sufficiently covered the practical case, so far as the pipe was concerned. In answer to a question respecting protective coverings, he said that those they had tested were found to be of no value, in fact they were detrimental, because they tended to concentrate the corrosion. Extremely heavy layers of pitch would give protection for a considerable time, but it was doubtful whether the cost was justified.

H. R. S.

Dielectric Strength of Thin Insulating Materials.

F. M. Farmer.

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 2191-2205.)

Experiments made to determine the effect of electrode-area on the insulating strength of thin sheets are described. The electrodes used were needle-points and flat round disks $\frac{1}{64}$ to 15 inches in diameter, and some of the dielectrics used were varnished cambric in air and under oil, hard rubber, black varnished cloth in air and in oil, and also air and oil. In the case of varnished cambric about 13 mils thick in air the average puncturing voltage per mil with needles was 720. The maximum voltage was 1,395, and was obtained with $\frac{1}{8}$-inch electrodes, and the voltage was gradually reduced to

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[1] *See* Minutes of Proceedings Inst. C.E., vol. cxciv, p. 488.

625 with 15-inch electrodes. The corresponding figures per mil for hard sheet rubber 9 mils thick were 1,705, 1,970 and 1,055 (with 10-inch electrodes). The general conclusion was that the effect of the electrode-area on the puncturing voltage is only in part due to want of homogeneity in the material, and that in the case of smaller electrodes it is due to the change in distribution of the electrical stress. With very moist air there is no reduction in strength with small electrodes, probably due to moisture-films which increase the effective area of the electrode. With small electrodes the dielectric strength increases rapidly as the thickness of the material is diminished, as the electrode-area is increased the strength depends less and less on the thickness. It is pointed out that these tests indicate the necessity for a standard specification for testing insulating materials.

H. R. S.

Specification and Analytical Procedure for 30*-per-Cent. Hevea-Rubber Insulating Compound.*

(Proceedings of the American Institute of Electrical Engineers, New York, 1914, vol. 33, pp. 121-140.)

There has not, in practice, been much difficulty in obtaining rubber-insulation of sufficient dielectric strength, specific resistance, elasticity and mechanical strength. But the property of permanence is not easy to obtain, and it can often only be proved after great loss, inconvenience and even danger. A Committee appointed by a group of manufacturers and users of rubber-compound has prepared a specification of tests devised with the object of ascertaining the quality of permanence. The difficulties of preparing such a specification are explained, and it is pointed out that a specification based only on tensile strength and elasticity is unreliable, as it can be complied with by manufacturers by using materials of poor quality. Reliance must be placed on chemical tests, which to be effective must specify the analytical methods in detail, so that different chemists can apply them and derive uniform interpretation therefrom. A short account is given of various kinds of rubber, and how they should be collected to obtain satisfactory results. The apparatus for preparing the samples for chemical test is described with fully dimensioned drawings. Analytical methods are given dealing with such materials as unsaponifiable resins, hydrocarbons, etc. A Table shows the way in which the results should be presented. The specification is based on the fact that a composition containing Hevea-rubber is of great durability. There is a list of those materials which must be excluded and those which must be minimized in quantity.

H. R. S.

Suspension-Insulators for High Voltage. J. R.

(La Lumière Électrique, Paris, 1913, vol. 24, pp. 408-412.)

The Vedovelli-Priestley suspension-insulator is described, and it is shown that a chain of such insulators is capable of resisting considerable tension, and that it will not allow the line to fall should the porcelain be fractured. The insulation is not seriously diminished by mere deposition of moisture, but is much reduced by water running over the face of the porcelain, as would be caused by heavy rain. In ordinary insulators protection against rain is provided by a large porcelain petticoat on the top of the insulator, which is costly and easily broken. In the chain of insulators under description four insulators are placed in series under a large metal umbrella, arranged so as to protect them entirely from heavy rain striking at an angle of 30° from the vertical. A number of such chains, each with its own umbrella, are placed in series according to the voltage to be dealt with. A large number of small insulators are recommended in preference to a few large insulators, because in case of breakage or failure in one insulator a smaller percentage of the total resistance is lost. The article is illustrated.

H. R. S.

Factory-Lighting. M. H. Flexner and A. O. Dicker.

(Transactions of the Illuminating Engineering Society, New York, 1913, vol. 9, pp. 470-487.)

The general principles of adequate factory-lighting are discussed, and it is shown that the cost of such lighting is under 1 per cent. of the wages of the workmen, whereas by its means the increase in output is at least 5 per cent. It is stated that for very good lighting a 100-watt lamp is required for each 100 square feet of working area, which is the average space required by a workman. Several examples are given to prove these points; the cost of electricity and wages being in accordance with American practice.

H. R. S.

Cooling Effect of Leading-in Wires on the Filaments of Tungsten Glow Lamps of the Street Series Type. T. H. Amrine.

(Transactions of the Illuminating Engineering Society, New York, 1913, vol. 8, pp. 385-399.)

Tungsten wire can now be drawn so accurately that for a definite number of watts per unit-length a definite candle-power is produced. The cooling effect of leading-in wires and anchors, however, reduced the average candle-power per unit of length, and the above relation becomes, in practice, indefinite. The investigation described was directed to find this cooling effect in the case of low-voltage high-current lamps. The difficulties in calculating or measuring the temperature of the filament at different distances from the cooling points are stated, and hence the experimental method adopted was by comparing two exactly similar lamps, differing only in length of filament, and by taking photometer and watt-meter measurements. It is shown how the average percentage candle-power and the average percentage wattage for the cold portion of the filament can be obtained. The figures were combined into one quantity, viz., the result of the cooling effect on both the candle-power and the wattage of the filament. The effects of the length of the diameter of the filament and of the diameter of the leads were measured in numerous cases, and the results are presented in graphic form. The cooling effect of the leads is such that the lamp does not come up to full normal candle-power for several minutes, and errors of over 6 per cent. can be made in photometering if the readings are taken before the lamp has had time to become thoroughly heated.

H. R. S.

The Moore Light. J. Buges.

(Elektrotechnische Zeitschrift, Berlin, 1914, vol. 35, pp. 57–61.)

It is pointed out that the light from metal-filament lamps emanates from an incandescent surface, and that from a Moore tube from a volume of glowing gas. Comparative polar-curve diagrams of intensity of light from metal-filament lamps and from a section of a Moore tube are given, as obtained from experiment; and from them it is shown how the illumination at a given point can be calculated in each case, and further, that the ratio of the horizontal to the spherical candle-power is 0·99 in the case of the Moore light, as against the usual 0·79 for a metal-filament lamp. From these data the total illumination on the floor is calculated. In a room having mat black walls and ceiling a Moore tube giving 50 candle-power per metre was arranged in the form of a square 3 metres above the floor and placed eccentrically in the room. Metal-filament lamps were also placed at 2-metre intervals in the same line as the tube, each of 100 candle-power. It is shown that the total illumination produced by the Moore tube is about 570,000 lux, and that by the metal-filament lamps about 479,000 lux, or taking 1·5 watt per Hefner candle for the Moore light, and 1·1 watt per Hefner candle for the metal-filament lamps, the latter give 12·8 per cent. better efficiency in illumination in respect of the power required. Comparisons are also made with the tube and the lights 5 and 7 metres above the floor, and with the filaments of the lamps placed horizontally and vertically, and the conclusion is that the Moore light is equal to the metal-filament lamp when the filaments are placed horizontally, and far superior when they are placed vertically.

H. R. S.

Silver Voltameter. E. B. Rosa and G. W. Vinal.

(Bulletin of the Bureau of Standards, Washington, 1913, vol. 9, pp. 151-282.)

A brief history of the use of the silver voltameter for the accurate measuring of electric current is given, with a short account of the various methods adopted. Preliminary experiments showed that the purest silver nitrate obtainable was not quite pure enough for the highest precision, and this led to a new method being devised for purification. The work described was carried out between October, 1908, and April, 1910. The preliminary work is described in Part I, and certain conclusions were arrived at, the most important being that filter-paper caused a slightly greater weight of deposit and had a marked effect on the appearance of the deposit, making it striated instead of granular. Several photographs illustrate this effect. In order to determine the cause of this striation, many substances were added to the electrolyte; for example, copper, salts, colloidal silver, cane-sugar, starch, furfuraldehyde, phenol, etc. Observations of the deposit were made with a binocular microscope, and numerous photographic reproductions are given. It was thus found that the striation caused by filter-paper is due to furfuraldehyde. There is a long discussion on the subject.

H. R. S.

Acceptance-Tests of Watt-Hour Meters in New York.

(Electrical World, New York, 1913, vol. 62, p. 941.)

New regulations governing the acceptance-tests of watt-hour meters have been issued by the New York Public Service Commission, First District. They came into effect on the 30th September, 1913, superseding those issued in 1909. The specifications for accuracy of direct-current meters provide for seven tests, relating to initial accuracy of registration, effect of variation in voltage, equality of elements in three-wire meters, effect of external magnetic fields, effect of variation in temperature, effect of temporary overloads, and voltage drop in series coils. For the accuracy of single-phase induction-meters the specification includes two tests, in addition to those provided for direct-current meters, namely, the effect of variation in power-factor and the effect of variation in frequency. These specifications are drawn up in a form showing the maximum permissible deviation from 100 per cent. on a continuously-running basis.

P. T. S.

The Kilowatt is the Unit of Power in the Metric System.

G. Darrieus.

(La Lumière Électrique, Paris, 1913, vol. 24, pp. 336–337.)

It is shown that the not unusual idea that the kilowatt is an electrical unit is erroneous, and that in reality it is the natural power-unit of the metric system, provided the standard kilogram be regarded, as it originally was, as the unit of mass, so as to make the power-unit independent of locality. The kinetic energy of 1 kilogram (mass) whose velocity is 1 metre per second, is ½ joule. Hence the kinetic energy of 1 ton (metric) whose velocity is 1 metre per second, is ½ kilowatt per second. Two numerical examples are given to show the simplifications resulting in taking the kilowatt, instead of the horse-power, as the power-unit. One has reference to an Ilgner fly-wheel, and the other to the gyroscopic effect of a turbo-dynamo running parallel to the keel of a vessel rolling in a sea-way.

H. R. S.

Starting Resistances.

(Elektrotechnische Zeitschrift, Berlin, 1913, vol. 34, pp. 1251–1258.)

The object of this article is to give information not usually available and to determine the resistance-steps of a motor-starter so that there will be no undue rise of current, the temperature of the resistance-wire will not rise above a safe limit, and the minimum amount of material will be used. The principles involved are explained by means of diagrams, and a Table is given of the percentage amount of material which should be placed in each resistance-step. Thus, when there are seven steps, the percentages are, beginning at the first step, 26·5, 25, 20, 12·5, 7·5, 5 and 3·5. Special attention is paid to the case of intermittent switches for use with crane-motors, for example, and it is shown that the heating of the resistance-steps depends on the ratio between the time of rest and the time it takes to operate the switch. It also depends on the rate of cooling, and it is recommended that the cooling curve should be obtained experimentally.

H. R. S.

Working-Efficiency of Mercury Rectifiers. J. Epstein.

(Elektrotechnische Zeitschrift, Berlin, 1913, vol. 34, pp. 1415–1420.)

This rectifier, rated at 240 volts and 360 amperes, was installed in the works of Messrs. Frederick Mack, and replaced an original direct-current supply from a neighbouring works. The power is required for driving motors and varies considerably during the day, the maximum power being about 61 kilowatts and the normal load about 33 kilowatts. A load-curve shows the typical power-supply characteristics. To measure the efficiency, wattmeters were placed in the conductors to both poles and also in the rectified circuit, and a diagram of the connection is given. The results are stated with, and without, the exciting transformer and the air-pump for obtaining a vacuum in the rectifier. The various losses are also measured and tabulated, and at 60 kilowatts, for example, amount to 0·95 kilowatt. The working-efficiency at 60 kilowatts output was found to be 86 per cent. and at 30 kilowatts 84 per cent.

H. R. S.

High-Power Mercury Rectifiers. K. NORDEN.

(Elektrotechnische Zeitschrift, Berlin, 1913, vol. 34, pp. 1479-1482.)

A short account is given of the development of the high-power mercury rectifier, in which steel containers are used instead of glass or quartz. The 1913 model of the Allgemeine Elektricitäts-Gesellschaft is then described in detail, together with efficiency-tests made by Professor Lorlich. This model has a capacity of 100 kilowatts and rectifies three-phase current. It consists of a central cylinder about 1 metre high and 415 millimetres in diameter, at the bottom of which is placed the mercury. The cylinder is surrounded by a cooling water-jacket. The cooling effect, however is not due to circulation, but to evaporation of the water. Three steel pipes are welded near the bottom of the cylinder, issue radially, and then turn up vertically. Each contains an iron anode, one for each phase, duly insulated by means of porcelain and mica. In the efficiency-tests wattmeters were placed in each phase, and also in the circuit of the rectified current; 100 kilowatts were maintained for over 4 hours; there was no undue heating, and the average efficiency was slightly over 90 per cent. Oscillograms are given of the alternating and of the rectified circuit. It is stated that 1,000-kilowatt rectifiers of a similar type are being built by the General Electric Company in America.

H. R. S.

Propagation of Surges and the Characteristic Accidents caused by them in Electric Transmission-Lines. G. CAPART.

(La Technique Moderne, Paris, 1913, vol. 7, pp, 289-297 and 344-351.)

The conditions leading to surges in transmission-lines are discussed, starting from first principles. Equations are found from which the voltage of such surges can be obtained, and a summary of present knowledge on the subject is given. A case is considered in which a wave with a steep front travelling in a portion of the circuit having a given inductance and capacity enters another portion of the circuit having a different inductance and capacity, and the effect of varying these given values is considered. In all cases when the resistance is negligible the current and pressure wave-fronts, both of the entering and reflected wave, are perpendicular to the direction-travel, and in some cases the pressure is greatly increased. It is then shown that the effect of a resistance of a capacity, or of an inductance separating the two portions of the circuit, is to flatten the wave-front. A steep wave-front is liable to cause damage by subjecting adjacent coils of a machine to a greater difference of potential than the insulation is capable of withstanding. The Author then shows that the flattening of the wave-front by means of a resistance is difficult, and that the required inductance is impracticably great, but that a comparatively small capacity is satisfactory. From this basis the capabilities of various protecting-devices are discussed and criticized. The article concludes with descriptions, accompanied by photographs, of numerous accidents which have been caused by surges to insulators and coils of electrical machinery.

H. R. S.

Calculations and Measurements on Long Transmission-Lines.

U. Del Buono.

(Atti dell' Associazione Elettrotecnica Italiana, Milan, 1913, vol. 17, pp. 999-1053.)

The Author transforms and simplifies the fundamental equations for the transmission of electric energy, and expresses the amount and electromotive force in terms of certain coefficients which are themselves functions of the line-constants. This method facilitates a graphical solution of the problem, and a large number of explanatory diagrams are included. The "Ferranti" effect is discussed at some length, and it is shown that the ratio of generated to received electromotive force on open circuit is equal to the ratio of generated to received current on short circuit. The Author then describes measurements which he has made on the Pescara–Naples line (length 120 miles, voltage 90,000). These measurements show that the proposed method of calculation gives extremely accurate results.

L. F. M.

100,000-*Volt Transmission into Bombay.*

(Electrical World, New York, 1913, vol. 62, pp. 950-955.)

A description is here given of a power-plant and transmission-line to supply electrical energy to Bombay, chiefly for cotton-mills. The power-house, which is designed for an ultimate output of 66,000 kilowatts, is situated 2,000 feet below the water-supply and 43 miles from Bombay. The article describes, with drawings and maps, the storage-lakes and 4-mile masonry duct, the steel pipe-line to the power-house, the power-house at Khopoli, the transmission-line, the receiving-station at Bombay, and the motor-equipment in mills. Power is generated in units, consisting of 11,000-HP. Escher-Wyss horizontal impulse-turbines, running at 300 revolutions per minute, coupled to 8,000-kilowatt, 5,000-volt, 50-cycle, 3-phase generators capable of 20 per cent. overload for 10 hours. Details are given of the power-house plant and transformers at both ends of the high-tension transmission-line, and the current is stepped down to 6,600 volts at the receiving-station.

P. T. S.

150,000-*Volt Development at Big Creek, California.*

(Electrical World, New York, 1914, vol. 63, pp. 33-38, 85-88.)

The Big Creek rises in the Sierra Nevada, California, and drains an area of about 88 square miles. The annual rainfall is over 80 inches and the run-off about 50 inches. The river has a drop of 4,000 feet in 6 miles which has been utilized in two power-plants. The effective heads on the wheels are 1,900 feet and 1,780 feet for the two plants respectively. The average daily flow is about 300 cubic feet per second. These plants present several unusual features, owing to the hydraulic head used, the amount of power developed, the distance and voltage of transmission and the provisions for regulation on the lines. The lines are designed for 150,000-volt service, and transmit an aggregate of 120,000 kilowatts to Los Angeles, 240 miles away. The dams and hydraulic features, discharge-tunnels and pipe-lines are described, as well as the generating and switching equipment and the transmission-lines. The power is generated in units of a 17,500-kilovolt-ampere generator, directly connected to two impulse-wheels of 10,000-HP. rating each, the wheels being overhung outside the bearings carrying the shaft. They are 94 inches in diameter on the impulse-circle and the water is directed upon the buckets by means of a stationary nozzle with a governor-controlled needle-valve. Details of the whole equipment are given, with photographs and drawings, and in order to maintain the pressure of 150,000 volts at both ends two 15,000-kilovolt-ampere synchronous condensers are installed at Los Angeles to neutralize the power-factor and voltage-effects introduced by the capacity-reactance of the long transmission-line.

P. T. S.

Methods of Determining Losses in Apparatus.

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 2006-2052.—Mid-winter Convention Papers (Discussion)—Group 2.)

This Group dealt with the methods of determining losses in induction-motors, transformers, generators and brushes. Mr. B. G. Lamme, in summing up the discussion, said that the Committee appointed to revise the standardization rules of the Institution felt that many of these could not be defined correctly, and so many changes were suggested that it was decided to present the matter for open discussion by the reading of the numerous papers dealing with the various points in question. The result of that discussion had been to show a possibly exaggerated view of the inaccuracy of many of the measurements, which, from one point of view, was discouraging; but, on the other hand, if accurate determinations cannot be obtained, it was better that it should be known. There was much discussion as to nomenclature. Mr. H. M. Hobart defined "load-loss" as increasing as the square of the current, and wished to add the term "stray losses," to indicate those losses which had to be added to the no-load loss and the "load-losses" in order to obtain the input at full load. Other suggestions were made in this direction, but no conclusion was arrived at. In respect of transformers, Mr. C. P. Steinmetz stated that the I^2R loss of the exciting current should be separated, and not included in the core-loss. Mr. P. M. Lincoln said that the standard air-temperature should be taken at 25° C. In respect of brush-losses, Mr. Alexander Gray gave an account of experiments he had made, and stated that the brush-friction increased considerably owing to a film which gradually formed, but could be removed by holding a piece of waste on the collecting ring, or by a little vaseline. The increase of friction-loss due to this film was as much as 300 per cent. Mr. B. G. Lamme's opinion was that all the methods suggested up to the present "must be considered as only rough approximations."

H. R. S.

Methods of Testing Apparatus for Performance.

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 2053-2072.—Mid-winter Convention Papers (Discussion)—Group 3.)

This Group dealt with the methods of testing generators, induction-motors and transformers. Mr. P. M. Lincoln pointed out that, owing to the size of generators (10,000 to 20,000 kilovolt-amperes), full-load tests at the manufacturers' works were of extreme difficulty, and it was therefore important to obtain a method as a substitute for the zero power-factor test. The Paper read indicated that the "alternate open-circuit and short-circuit operation" method promised to give results in heating, equivalent to the actual load-test, and that this method might be safely included in the Standardization Rules. Mr. B. A. Behrend advocated the "split-field" method which was fully described at the St. Louis Conference in 1904. He was of opinion that these equivalent tests should not be embodied in the Standardization Rules, as it would lead to endless discussion and disagreement. Mr. Stuart L. Henderson was of opinion that the intermittent short-circuit and open-circuit tests did not work well in practice, owing to the difficulty of obtaining reliable temperatures.

H. R. S.

Miscellaneous Subjects relating to Rating.

(Proceedings of the American Institute of Electrical Engineers, New York, 1913, vol. 32, pp. 2073-2121.—Mid-winter Convention Papers (Discussion)—Group 4.)

This Group dealt with oil-switches, spark-gaps, wave-form and regulation. It was generally agreed that for voltages over 50,000, the standard needle-point gap was unreliable and the sphere-gap method was much to be preferred. Mr. C. P. Steinmetz thought that up to 20,000 volts the needle-gap method would remain the standard, but that the sphere-gap would be used beyond that amount. Mr. S. W. Farnsworth quoted experiments made by Weicker, showing that in the case of sphere-gap humidity had no effect; the sparking voltage was inversely proportional to the absolute temperature and directly proportional to the barometric pressure. It was not affected by frequency within the commercial ranges of 20 to 75 cycles. Mr. P. H. Thomas thought that for frequencies of 10,000 or 100,000 cycles it would be necessary to have no resistance in series with the gap. He also referred to the time-lag of the spark, to which Mr. C. Fortescue replied that with a needle spark-gap there was appreciable lag for very high frequencies, but none in the case of the sphere-gap. Mr. Leo Schuler, who attended the meeting as representing the German Standards Committee, hoped that the American and German Standardization Rules could be made to agree, and said, "If you will consider that the world's market of electrical machinery is practically controlled by the American and German firms, you will understand the importance of such an agreement in the Standardization Rules."

H. R. S.

Experiments connecting Wireless Telegraphy and Atmospheric Electricity.

(Jahrbuch der Drahtlosen Telegraphie und Telephonie, Leipzig, 1913, vol. 7, pp. 521-534, 589-603.)

Experiments were made at Gräfelfing, near Munich, from the spring of 1907 to the spring of 1911 to deal with the effect of electrical disturbances on a receiving aerial. The apparatus used was placed at different points in a large field, and consisted of a small sending-station, various types of receiving-apparatus, aerials of various types and a captive-balloon equipment. To determine the change, due to the aerial, in the equipotential lines in the atmosphere, an artificial field was formed with two electrified plates having a difference of potential of 300 volts between them. Various types of aerials were introduced between the two plates and the run of the equipotential lines was then measured. The results are plotted and show the effect of a vertical aerial, a ship aerial, an umbrella aerial, and an airship fitted with wireless telegraphy. Various suggestions are made as regards means for protecting an aerial from atmospheric disturbances, based on the Faraday Cage principle. For instance, it is suggested that over a horizontal aerial a system of wires be placed arranged so as to be non-oscillating. It is argued that such a protection would interfere but slightly with the radiation of the electro-magnetic waves from the aerial. H. R. S.

Wireless Telegraphy on the Lackawanna Railroad.

J. L. Hogan, Jun.

(Electrical World, New York, 1914, vol. 63, pp. 89-91.)

The Delaware, Lackawanna and Western Railroad has recently established communication by means of wireless telegraphic apparatus between stations and a moving train. Fixed stations have been established, one at Scranton and the other at Binghampton. On the train the antenna is formed from four rectangles of wire, each of which is carried on insulators at the corners of one of the four forward coaches; these are linked up between the coaches, and form a "flat top" about 250 feet long, 10 feet wide and 12 feet above the rails. It is now possible to communicate with stations in New York until the train reaches Dover about 40 miles out. Fifty-three miles farther signals may be sent from the train to Scranton, about 50 miles away. Signals from Scranton are picked up when the train is 30 miles away, and the train, after passing Scranton, gets in touch with Binghampton 62 miles away. Details are given of the apparatus on the train and at the stations, and it is mentioned that no interruption occurs as the train runs through a tunnel about 700 feet long and some 60 feet below the earth's surface.

P. T. S.

Calculation of the Stopping Distance of Steamers.

E. DE GEOFFROY.

(La Technique Moderne, Paris, 1914, vol. 8, pp. 8–12 and 62–67.)

The general differential equations of the motion of a vessel are derived, and an expression is obtained for the resistance to motion of the hull, based on theoretical consideration, but requiring several empirical coefficients. The way in which these coefficients vary with speed and with the shape of the vessel, etc., is discussed, and numerical data are given, based on the experiments of Froude, Risbec and others. A formula for the retarding effect due to reversal of the engines in the case of paddle-wheels and screw-propellers is then given, and finally a formula is obtained by means of which the distance in which a vessel will stop, from the moment the engines have been reversed, can be computed. This formula is then compared with the results obtained with a cross-channel paddle-boat, with the *Provence*, a twin-screw steamer driven by reciprocating steam-engines, and the *France*, a quadruple-screw steamer driven by turbines. In the case of the paddle-boat the calculated stopping-distance was 184·2 metres, and the actual distance 180 metres, or 1·79 time the length of the boat. In the case of the *Provence* the calculated distance was 2·2 times the length. In both these cases the engines developed the same power in either direction. With the *France*, assuming equal power ahead and astern, the calculated stopping-distance is 1·8 time the length of the vessel, but with a turbine-steamer the power astern is less than the power ahead, and if it is taken at $\frac{4}{10}$, then the calculated stopping-distance is 2·7 times the length. It will be seen that if the ahead and astern power of turbine-steamers were made equal, the stopping-distance would be the same as with paddle-wheels or screw-propellers driven by reciprocating-engines.

H. R. S.

Electrically-operated Ship "Tynemount."

(Electrical World, New York, 1913, vol. 62, pp. 947–949.)

The *Tynemount*, which was recently built in England and is designed to work on the Great Lakes of North America, is 250 feet in length and 42·5 feet in beam, with a draught of 19 feet. Her prime movers consist of a pair of six-cylinder Diesel-type engines, each capable of developing 300 B.HP. at 400 revolutions per minute, totally enclosed with forced lubrication throughout. The engines are direct-coupled to three-phase alternators designed on the Mavor system, each generating 500 volts, and provided with six and eight poles respectively. These make the frequency produced by one 20 cycles per second and by the other 26·6 cycles per second. The output from these two generating-sets is led to one 500-B.HP. induction-motor of special construction, the stator being provided with two entirely separate windings, one having thirty and the other forty poles. When both windings are supplied with the two currents they give the same synchronous speed of 80 revolutions per minute. The motor is direct-coupled to a single propeller, and this corresponds to the fastest speed of the vessel. To obtain a lower speed of 60 revolutions per minute the 20-cycle alternator only supplies the forty-pole winding, and the 26·6 cycle can be shut down. The motor is reversed by interchanging the connections of two of its phases. The switching-apparatus is interlocking and fully described, and the article is accompanied by photographs of the ship and the apparatus.

P. T. S.

New Type of Motor-Boat, "The Tempelhof." G. LANDSBERG.

(Zeitschrift des Vereines deutscher Ingenieure, Berlin, 1913, vol. 57, pp. 1769–1776.)

This motor-driven pleasure-steamer is the result of twenty-three competitive designs submitted with a view to reducing the wave-action on canal- and river-banks to a minimum. Diagrams from a wave-recorder showed that the depression and first wave increase very rapidly when a critical speed is exceeded. The critical speed varies for different steamers and was shown to depend on the maximum contour-line of the hull. Experiments were made with one-fifth full-size paraffin models at the Royal Testing Laboratory for Naval Architecture and Hydraulics. The profile of the canal was produced in wood and fixed in the test-trough at the laboratory. The best results were obtained with a shallow-draught, flat-bottomed model, with obtuse stern and bow. A boat was built on these lines and fitted with petrol-engines and reversible propeller, controlled from the bridge. The wave-records taken showed a reduction of 64 per cent. in depression-effect and of 33 per cent. in maximum wave-effect at a speed of 6·25 miles per hour; at higher speeds the reduction was still more marked. The new type of boat carries twice as many passengers as those previously employed. Drawings of the various models submitted accompany the article.

C. J. G.

Auxiliary-Motor Sailing-Ship "Morten Jensen." JESS. JESSEN.

(Ingeniören, Copenhagen, 1913, pp. 645–648.)

The vessel described is a four-masted fore-and-aft-rigged schooner of 800 tons displacement and fitted with an auxiliary motor of 160 HP. It is pointed out that the power of the motor is large in proportion to the sail-area, and that it enables the vessel to keep time on her voyages, to enter and leave port unassisted, and also to rank as a steamer at docks and quays for loading and unloading taking precedence of sailing-ships. The vessel is 135 feet long, 30 feet wide and 11 feet deep, register tonnage 290 and loading 500 tons dead weight. The engine-room is abaft of the hold and partly under the after-saloon. The engine is a direct reversible two-stroke two-cylinder motor, developing 160 B.HP. at 225 revolutions per minute. Reversing is effected by injecting and firing a charge of fuel on the up-stroke, whereby the piston is driven back and the shaft revolves in the opposite direction. A diagram shows the arrangement of the fuel-pump and the means adopted for reversing. The motor is started by compressed-air from a reservoir. The fuel-consumption is about ½ lb. per horse-power-hour. Auxiliary machinery, winches, etc., are driven by a 10-HP. motor. On the trial-trip the speed attained under motor-power only was 8 knots per hour, with motor and sails 12 knots in a fresh breeze. A detailed comparison as regards economic results between an auxiliary-motor ship and a sailing-ship is given, and shows a substantial advantage in favour of the former. It is pointed out that much of the success depends on the man in charge using motor and sails to the best advantage.

L. S. Z.

Lighthouse Systems for Aerial Navigation.

(Deutscher Luftfahrer-Zeitschrift, Berlin, 1913, vol. 17, pp. 597–604.)

Comparative experiments were carried out at Johannisthal with three different systems of lighthouses for aviation purposes, and the need of some proper system of guiding pilots by night is insisted on. The errors in past practice are discussed, and a diagram explains the difficulties caused by the alteration in altitude of the observer. As a rule the aviator travels at a height of 550 to 875 yards, but the light should be sufficiently powerful to be observed at a height of 4,300 yards. The use of colours (red and green light) seems necessary for identification, but entails great loss of light-intensity. It might be possible, using white light only, to denote localities by intermittent flashes, long and short, on the Morse system. In order to be equally visible from all points of the compass the lenses must rotate on a vertical axis, as in the case of lights at sea. Illustrations are given of a number of types of apparatus introduced for giving light to air-ships by night, including the first lighthouse installed in Germany, on the Pintsch system. An electric light with a ventilated cap-shield is also explained by reference to diagrams. A revolving flash-light, placed at an elevation of 236 feet, on a mast, serves to warn pilots of the presence of a high-tension conductor crossing the Elbe at Belgern. A method of lighting for landing-places, in which the source of light is placed below the surface of the ground, so as to avoid all danger to aviators, is illustrated and described. A full explanation, with photographs of the different types of apparatus, is given, showing the use of search-lights, with the method of directing the cone of rays. It is stated in conclusion that Germany has made a notable advance towards the solution of a problem which must shortly be seriously grappled with, namely, the provision of a uniform system of nocturnal lighting throughout the country.

G. R. R.

German Experimental Air-Ship "V. 1."

Dr. Herkerath and — Simon.

(Deutsche Luftfahrer-Zeitschrift, Berlin, 1913, vol. 17, pp. 556–560.)

A Company was formed in 1910 to test the inventions of Mr. Paul Veck, who had devised a non-rigid air-ship, somewhat of the Zeppelin type, in which it might be possible to omit the gigantic trussed framework necessary for these vessels. Although the original intention had been to construct an air-ship with a capacity of 495,000 to 530,000 cubic feet, it was decided from financial considerations to limit the size to 282,000 cubic feet, and it was not considered necessary under the circumstances to subdivide the gas-bag into separate cells. Some of the difficulties which beset the project are described. One of the main conditions to be studied was the possibility of ready deflation, so that the vessel could be dismounted and placed on a series of two-wheeled trucks for transportation. This entailed extreme lightness in the framework, and to demonstrate its rigidity the frame was subjected to various towage and other tests, here shown in photographs. It was also sent by rail from Munich to Düsseldorf, and it was experimentally tested in actual field-trials. The ship, named the *V.* 1, is of the semi-rigid type, with a trussed canoe-shaped keel, bent up at each end and coming to sharp points. This keel is formed of Mannesmann steel tubes 1·18 inch in diameter, and the vessel consists of two distinct parts—the keel and the gas-bag. The central part of the keel is shaped as a trapezium, and the ends are three-sided. The truss, which is of extreme rigidity, is covered with metallized balloon fabric, and weighs approximately only 12·43 lbs. per foot run, excluding the brackets for the propellers. The fore-cabin contains a 130-HP. Daimler motor, and a second motor of similar power is placed in the rear-cabin. Between them is the cabin for passengers. The hinder part of the truss supports the steering and stabilizing planes. The central keel-space contains benzine- and oil-reservoirs and spare ballast. The original capacity of the balloon has been increased to 321,000 cubic feet. Details of various trial-trips are given, and photographs show the completed air-ship.

G. R. R.

Landscape Photography from the Balloon for Surveys.

(Deutsche Luftfahrer-Zeitschrift, Berlin, 1913, vol. 17, pp. 569–574.)

Recent progress in aerial navigation has brought into prominence the experiments of Colonel T. Scheimpflug, whose aim it was to employ the camera directed earthwards from a considerable altitude to obtain true representations of the surface of the country for the purpose of the cartographer. Some of the difficulties encountered in the use of photography in this way are discussed. Even if the point of view is vertically over the picture the detail of the foreground is much more clear and distinct than that of the distant portion of the field, though in this way it is possible to obtain an accurate representation of the landscape scenery beneath the balloon. Difficulties are encountered when the picture is taken at an angle inclined to the vertical, as in this case the form of the area depicted is no longer rectangular but trapezium-shaped, and the matter is still more complicated when the camera is tilted sideways as well. Scheimpflug took his first photographs by means of kites, the cap of the camera being released electrically. It became necessary to transform these oblique views to vertical representations, and it is of course possible to do this when the angle of inclination is known. The apparatus devised for this purpose is shown and the optical laws on which the action is based are deduced. The instrument he employed, called the photoperspectograph, is illustrated. A panoramic camera taking eight pictures, one vertical and seven inclined, is also shown, together with its use on the car of the dirigible balloon *Austria.* Several photographs as originally taken and as corrected to the vertical position are appended to explain how the transformer is employed, and a map constructed from such photographs gives the practical application of the procedure. It embodies also a system of representing altitudes by Dr. Peucker.

G. R. R.

Scientific and Other Aspects of the Gordon-Bennett Balloon Contest of 1912. Dr. P. PERLEWITZ-HAMBURG.

(Deutsche Luftfahrer-Zeitschrift, Berlin, 1913, vol. 17, pp. 425–434.)

By reference to Tables, chart, and weather-diagrams, an account is given of the general results obtained by the twenty balloons, representing nine countries, which took part in the race for the Gordon-Bennett cup, starting from Stuttgart in October, 1912. These balloons remained upwards of 600 hours in the air, and traversed a distance of about 15,500 miles in 2 days and nights. The approximate track of each balloon is laid down on the chart, and the Author had the use of the log-books of all the pilots in order to arrive at the results given. He states that the comparison of the experiences of the different travellers is a matter of extreme interest, and gives information of much value. It is shown that the heights at which the balloons travelled were of much importance. The chart shows how greatly the air-currents varied in the course of the 2 days covered by the voyages in Eastern Europe and Russia. The mean heights attained were taken hourly from the separate barograms. From the synoptic weather charts for the 27th, 28th and 29th October, the condition of the atmosphere in the region traversed can be seen at a glance. From the fact that the majority of the balloons passed during the first night over a thick belt of clouds, it is not possible to lay down the actual routes with certainty; this was especially the case with those flying over Bohemia. The rapid changes in the weather experienced by the travellers are considered with reference to the meteorological diagrams. On the morning of the 28th October all the balloons, except No. 4 which had landed and No. 7, were able to ascertain their whereabouts. On the evening of the second day most of the balloons still in the air were over Western Russia. The abnormal courses of certain of the competitors are explained by a study of the heights attained. Thus balloon No. 3, which kept all the first night at altitudes as great as 7,000 feet, turned southwards into the Danube Valley towards Buda-Pest. Special attention is called to Table 3, which gives the times, heights, directions and speeds for all the balloons. A hope is expressed that in the case of future ascents of groups of balloons it may be possible to prepare similar statistics.

G. R. R.

Air-ship "Clément-Bayard VI." LUCIEN FOURNIER.

(La Nature, Paris, 1913, Deuxième Semestre, pp. 417-419.)

This air-ship is said to present many important improvements and to possess very superior steering qualities to any previously constructed. It is capable of making a vertical descent to earth and of effecting a landing without the aid of a trained staff. Special attention is called to the mode of suspending the car so as to diminish to the utmost the atmospheric resistance. The dimensions of the car itself have been greatly reduced and its attachments have been simplified. The total length of the balloon is 241·14 feet and the largest diameter 40·02 feet. The envelope is in two thicknesses; the inner fabric is coated with rubber and the outer material is coloured with chromate of lead and applied to the inner lining with a layer of gum. There is a cross-partition, which devides the gas-bag into two compartments, and the total capacity is 84,700 cubic feet. The envelope is provided with three ripping seams and with two valves in the rear. There are two horizontal steering-planes, fixed at the rear, having a total length of 55·76 feet. Each plane has a movable shutter which aids in determining the ascent. The keel-plane at the back is hinged on a horizontal axis with a vertical compensating surface, fixed in front, which facilitates the working of the steering-gear. The car formed of tubes and plates of steel is 32·8 feet in length. The two motors occupy the centre of the car, each driving a two-bladed screw-propeller 14·1 feet in diameter. A third screw, 6·56 feet in diameter, used for ascensional purposes only, is referred to as one of the chief novel features in the design of the balloon. The motors are of 150 HP. in all, and will propel the air-ship at a speed of 37 miles an hour. Illustrations are given of the balloon and its car, with the special motor-vehicles used for transportation of the car and for the detached screws and their supports. The balloon when tried on 31st July, 1913, was completely successful.

G. R. R.

Wear and Erosion of Gun-Barrels. A. Bourgoin.

(Mémorial d'Artillerie Navale, Paris, 1913, pp. 341-382.)

All recent attempts to increase muzzle-velocity have failed owing to the rapid erosion and wear of gun-barrels. The erosion at the breech-end is shown to be due to the high velocity and high temperature of the gases, both of which are calculated. The velocity of a projectile is also operative, because on it depends the time of exposure of each element of the surface being eroded. The wear at the muzzle is also discussed, and it is shown to be due to the radial pressures produced by the projectile straightening the bore, which is curved downwards by elastic deflection due to overhanging; these pressures are intensified by the vibration set up. It is shown that in a gun of 34 centimetres bore and 45 calibres, the overhang being 12 metres and the period of vibration $\frac{1}{140}$ second, the intensity of radial pressure from all causes is 34 kilograms per square millimetre. Photographs are given of the erosion at the breech-end and also of the markings on projectiles.

H. R. S.

Handling and Storage of Inflammable Liquids. P. Mauclère.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 1913, vol. 120, pp. 421-440.)

An account is given of the chief inflammable liquids in common use for industrial purposes, with a description of the mode of their preparation, and some reference to the great increase in the employment of such liquids in recent years. Among other matters mention is made of their use as motor-fuels, solvents for rubber and varnishes, for heating and lighting, and for the composition of many substances in the chemical industries, such as colours, perfumes, and the like. A Table shows graphically the chief sources of the supply of petroleum, and the enormous rise in the output, and a diagram indicates the amount of alcohol, petroleum (oil and spirit) and benzol consumed in France. Several systems of preparing alcohol from beetroot, potatoes, wood, and also synthetically, are described. It is shown that, as the bulk of the inflammable liquids are of foreign origin, it has been necessary to take special precautions for their transport and storage. Reference is made to the employment of pipe-lines for oil and to the use of tank-steamers. The Author discusses the regulations in force in different countries respecting the storage in bulk of inflammable liquids, and a special account is given, with illustrations, of the apparatus introduced by Rolland and Mauclère for the conveyance, handling and distribution of liquids of this nature without contact with air. In the first case the plant is described for the storage of the liquid hydrocarbons without provision for recovery of the inert gases employed, and a photograph and diagrams show the apparatus used for handling benzine. A special set of illustrations is given to show the arrangement of the plant used by the Paris Omnibus Company in their depot at Saint-Ouen, where the gases are preserved for re-use.

G. R. R.

Cause of an Explosion of Paper-Dust. P. M.

(Revue de Mécanique, Paris, 1913, vol. 33, pp. 582-585.)

An explosion of paper-dust occurred recently, killing two men. The paper-dust is due to the grinding of the edges of cardboard and is drawn away by air-suction and deposited in a large chamber which is cleaned out frequently, when an oil-lamp is used for illumination. Experiments were made at the Municipal Laboratory at Lille with an apparatus designed for studying explosions due to coal-dust. Dust-laden oxygen or air is blown through an aperture, and if the dust exceeds a certain amount a flame is obtained. It was found that paper-dust gave the same result as coal-dust containing 30 per cent. of volatile matter. Photographs of two such flames about 17 centimetres long are given. It was also ascertained that an explosion could not be produced by an electric spark, and it was finally decided that the explosion in question arose from air containing an unusually large proportion of dust having reached the flame of the lamp on this occasion.

H. R. S.

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Fig^s 6

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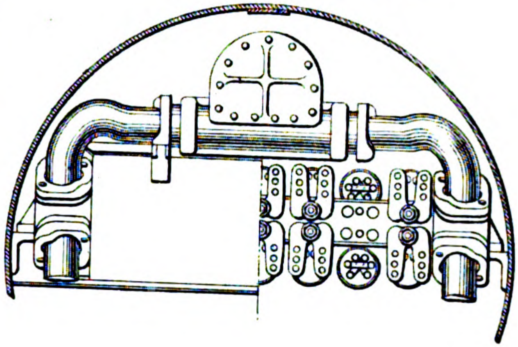
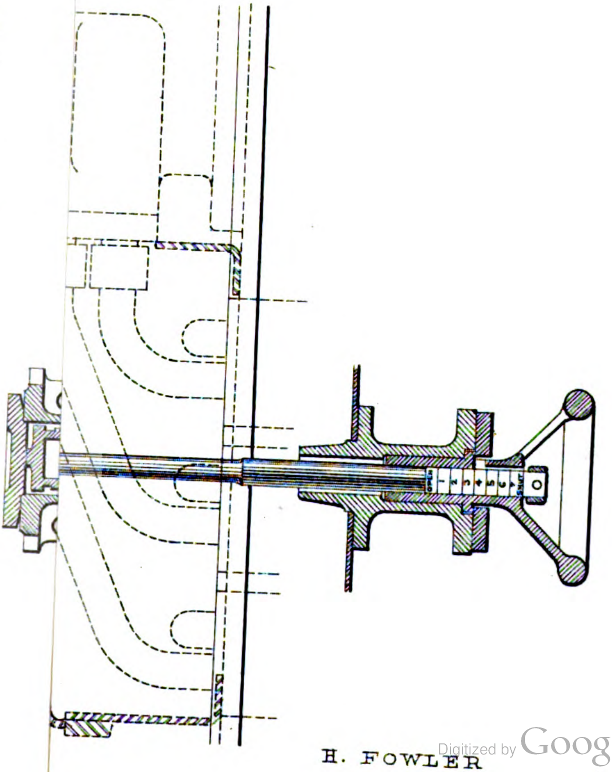
PLATE I.

SUPERHEATING STEAM IN LOCOMOTIVES.

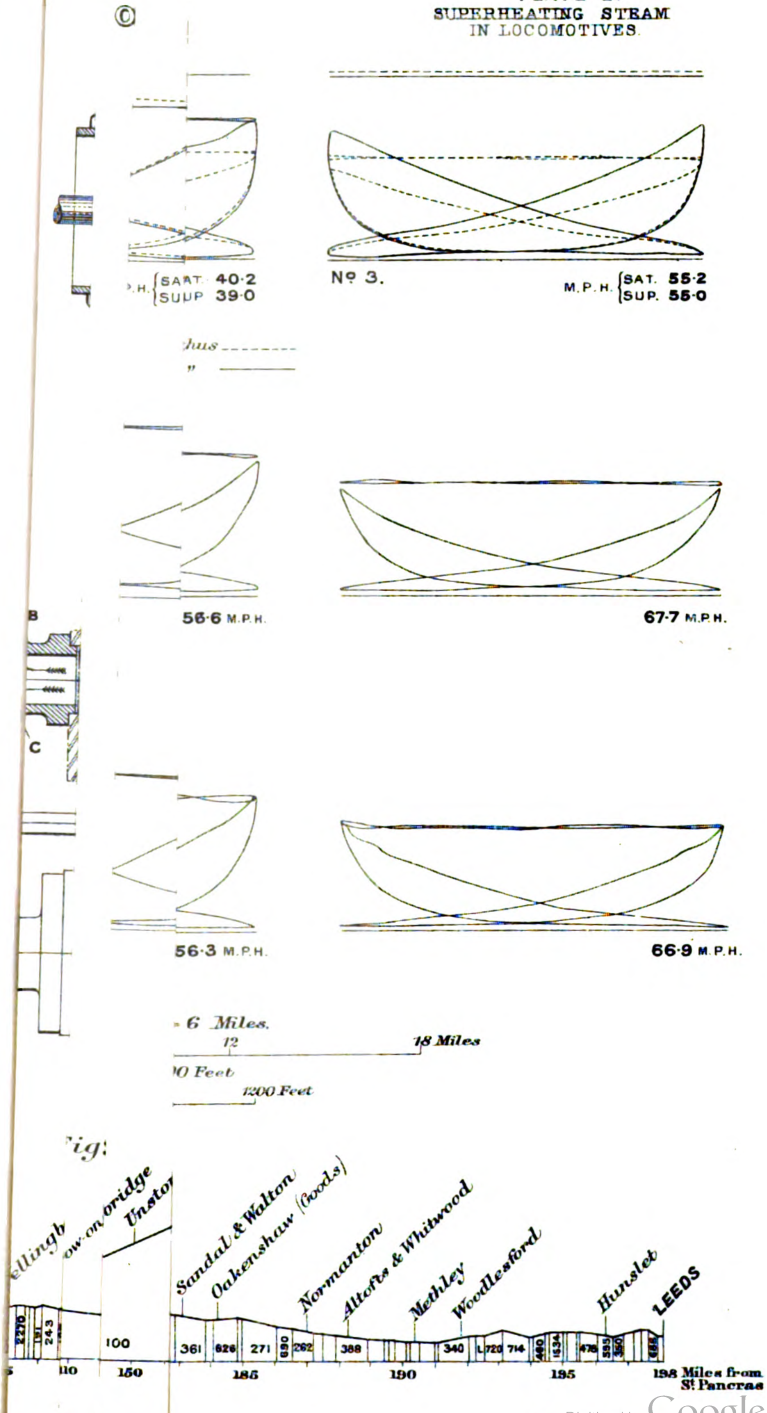




H. FOWLER

PLATE 2.

SUPERHEATING STEAM
IN LOCOMOTIVES.


©
.P.H. SAT. 40·2
SUP. 39·0
Nº 3.
M.P.H. SAT. 55·2
SUP. 55·0
hus
"
56·6 M.P.H.
67·7 M.P.H.
B
C
56·3 M.P.H.
66·9 M.P.H.
6 Miles.
12
18 Miles
0 Feet
1200 Feet
'ig:
ellingb
ow-on
bridge
Unston
Sandal & Walton
Oakenshaw (Goods)
Normanton
Altofts & Whitwood
Methley
Woodlesford
Hunslet
LEEDS
2270
191
243
100
361
626
271
690
262
388
340
L
720
714
460
1534
478
395
350
666
110
150
185
190
195
198 Miles from St Pancras

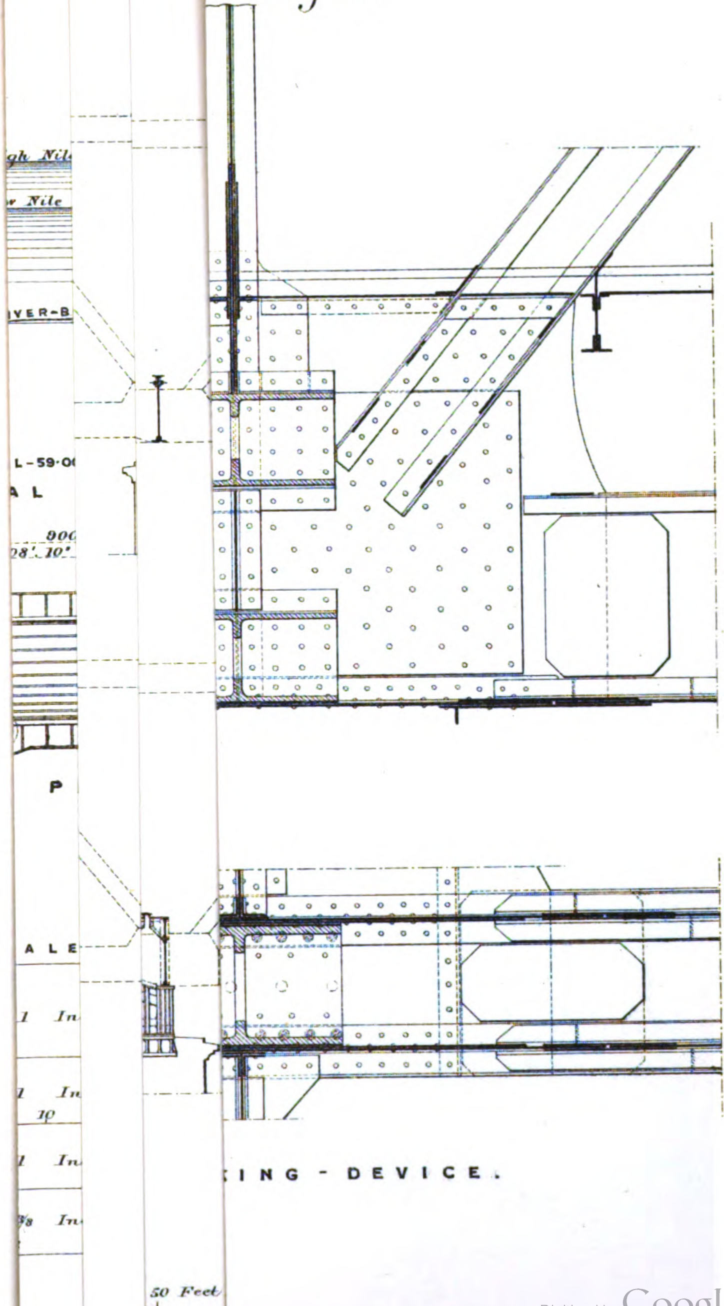
H FOWLER.

AT

F

PLATE 3.
OPENING BRIDGES
AT CAIRO.

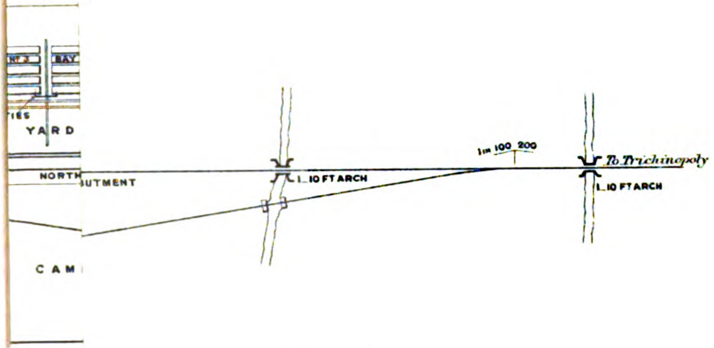
Fig: 6.


gh Nil
w Nile
VER-B
L-59·0
A L
900
28'.10'
P
ALE
1 In
1 In
10
1 In
⅜ In
50 Feet

KING - DEVICE.

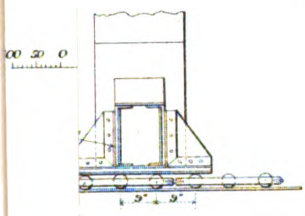
PLATE 4.

RENEWAL OF GIRDERS.

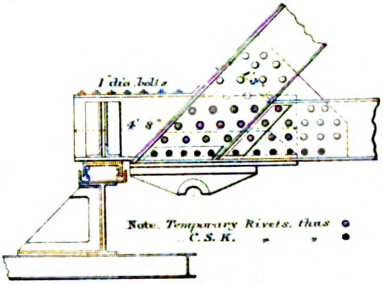


Nº 3
BAY
TIES
YARD
NORTH
UTMENT
1 in 100
200
To Trichinopoly
1 10 FT ARCH
1 10 FT ARCH
CAM

Figs 4.



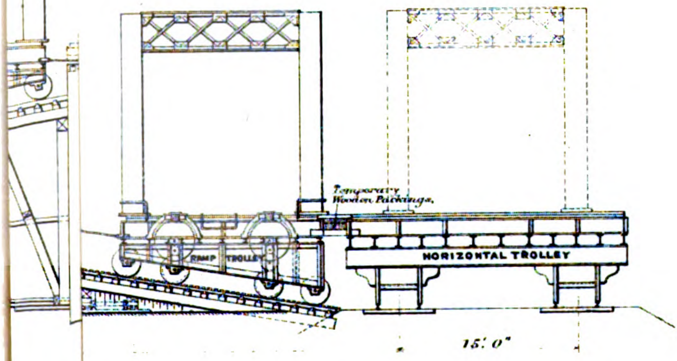
END ELEVATION.



1" dia. bolts
4' 8"
Note. Temporary Rivets, thus ●
C.S.K. " " ●

SIDE ELEVATION.

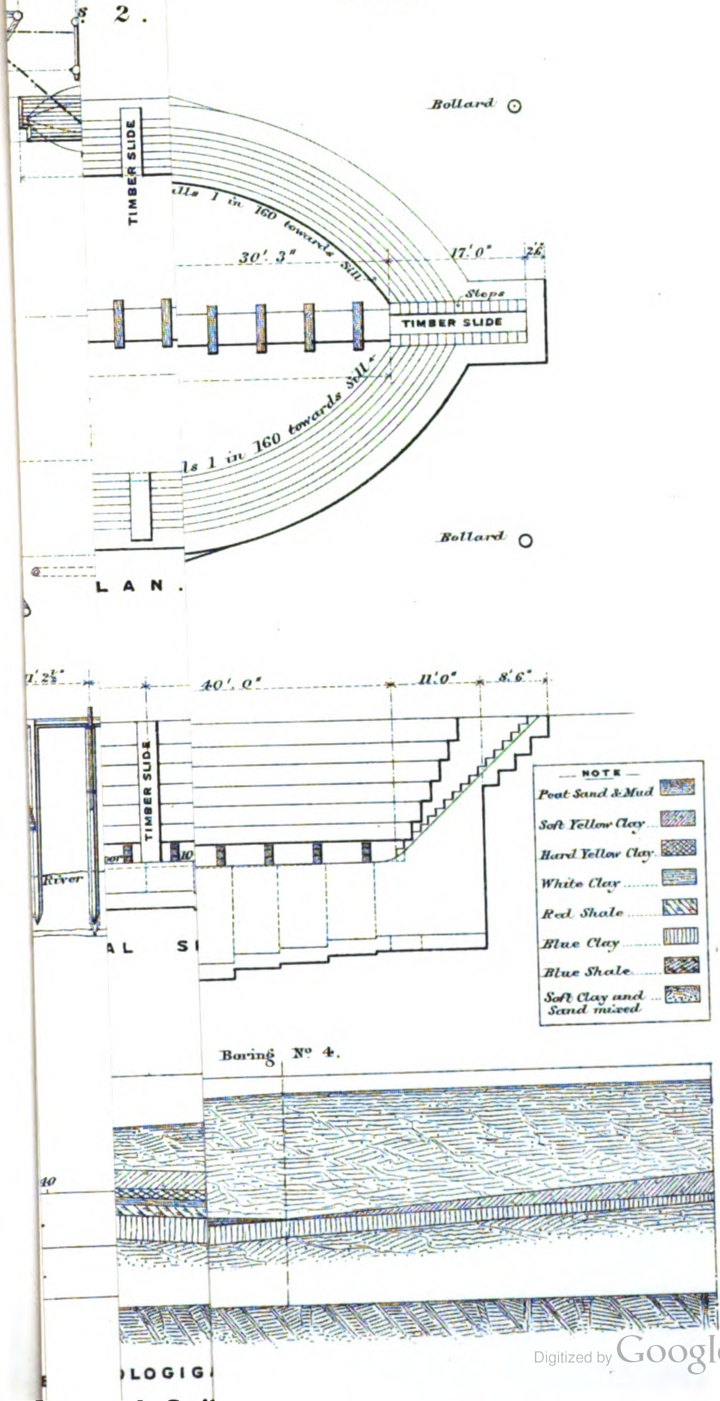
MPORARY EXTENSIONS.



Temporary Wooden Packings.
RAMP TROLLEY
HORIZONTAL TROLLEY
15' 0"

P. ROTHERA.

PLATE 5.
PUBLIC WORKS
KUCHING.



BLI
7'2½"
2.
Bollard
TIMBER SLIDE
lls 1 in 160 towards Sill
30'. 3"
17'. 0"
2'6"
Steps
TIMBER SLIDE
ls 1 in 160 towards Sill
Bollard
LAN.
1'2½"
40'. 0"
11'.0"
8'.6"
TIMBER SLIDE
River
AL S
NOTE
Peat Sand & Mud
Soft Yellow Clay
Hard Yellow Clay
White Clay
Red Shale
Blue Clay
Blue Shale
Soft Clay and Sand mixed
Boring No 4.
10
LOGIG

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